GAS POWER

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A STUDY OF THE EVOLUTION OF GAS POWER, THE DESIGN AND CONSTRUCTION OF LARGE GAS ENGINES IN EUROPE, THE APPLICATION OF GAS POWER TO VARIOUS INDUSTRIES AND THE RATIONAL UTILIZATION OF LOW GRADE FUELS

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TO THE PROMOTION OF SCIENTIFIC TECHNICAL EXCHANGE BETWEEN GERMAN AND AMERICAN INDUSTRIAL CIRCLES

PREFACE

Basing my observations on the belief that the success of an industry is not furthered by the maintenance, on the part of the producer, of unscientific secrecy, but rests rather on the broadcast dissemination, among progressive nations, of accomplished truths, on the reciprocation of enlightenment, on the exchange of valuable knowledge, in short, on the scientific spirit of enterprise aided by international technical coöperation, it is the object of this study to present to American engineers a critical survey of the field of gas-power generation, conversion, and application in Europe, as it exhibits itself at this present phase of development.

So far as theoretical and practical research have been able to analyze the very complex process of converting combustible matter into useful power directly and without the intervention of inefficient and passive machine parts, and so far as the technical literature of this country can be regarded as reflecting the light of these investigations, it is evident that the few scientific treatises available on the subject have been devoted to either one of the three aims: The abstract study of the internal thermodynamic relations of gas-producing and converting apparatus; the quantitative side of design of their mechanism; and the historical or inventive evolution of the problem.

All of these modes of treatment are interesting in themselves and valuable in their combination. Perceptibly the cultivation of the mechanical engineering part, that is, the theory of construction of gas producers and engines, as an expedient in the practical development of the art, is most vital to the question, greatly more so than is a purely hypothetical analysis of the physical and chemical phenomena occurring in the working cycle.

There is, however, one more side to the subject which so far has been entirely neglected and of whose want the trade is acutely conscious, namely, the broad economic aspect of the gas-power problem, its relation to the iron, coal, and kindred industries, and its scientific and impartial presentation to men, professional

and mercantile. It is the intent of this series of treatises to subject the last-named part of our theme to a searching analysis, and one which is purported to appeal to the interests of wider commercial circles — before all, to those men who project and exploit industrial enterprises. In demonstrating the possibilities and clarifying the limitations of the applications of gas power in the varied industries, it is hoped that they will recognize at once the far-reaching importance of our claimant as being one of the principal factors in the restless striving for industrial betterment which centers, besides in a number of ethical aims, in the two great practical goals: economy of methods and perfection of output.

To explain why Europe, and especially Germany, has made, in the utilization and conservation of fuels, such remarkable strides forward is easier for the foreigner than it is for him to analyze the obstacles which have been and are yet militating against a stable and healthy industrial growth of gas power in this country.

It is owing to the scarcity of natural resources, to the density of population, to the concentration of industries and to the keenness of competition, that the law of self-preservation has impressed itself with more weight on the responsible quarters of old Europe, and that the demand to economize by reducing waste in methods of production has forced itself earlier upon the German engineer than on any other tribe of our profession. And if I say that the records presented in this book refer to the performances of an industry which has reached a more advanced phase of development than any of its European competitors, it is only after years of comparative study that I feel justified in stating it so boldly.

In commending an approach of American modes of gas-power engineering to German standards I do not overlook the fact that inequalities in conditions, whether geographical, economical, or governmental, must largely affect the point of view and the judgment on questions that are of common interest in engineering matters. Especially will this be so when the comparison concerns the practice of two countries wherein the underlying basic conditions are so widely divergent.

I have also endeavored to keep in mind that there are but few industrial schemes — especially such as depend on the quality and characteristics of combustibles as a measure of performance —

which can stand a transplantation from their native territory without undergoing a lengthy process of assimilation and suffering considerable adjustment before evolving to a state of profitableness within the new locality.

Finally, I am quite conscious of the fact that there is no set of technical codes or rules or standards that will give unchallenged satisfaction everywhere and for any length of time, but that, sooner or later, they will be supplanted again by superior measures, since the rapid progress in arts and science must logically and gradually introduce such imperfections into present truths as we cannot now foresee.

Yet every consideration is subordinate to the idea that the preservation of our irreplaceable fuel resources is a common, international aim, the realization of which is apt to benefit the whole of mankind. And though it is quite true that the propounding, among foreigners, of events, however absorbingly interesting they be to the native student, will fail to command general attention abroad, so long as they are limited to any but the broadest problems, yet it is equally certain that there is none more vital for the present industrial activities of mankind, none more imperative for the life and prosperity of future generations, than the theme of providing adequate measures against the abuses which have been going on in the administration of public utilities, such as are the mineral fuels of the earth.

The importance of the question for operations within the national borders of this country is clearly designated in the policy, which was recently inaugurated by the United States government, and which aims toward preventing the passing of the natural supplies into private ownership and the control of corporations. To keep control of the coal lands by leasing and not selling them to the public, is the keynote of a presidential message recently delivered to Congress.

These are the principal points of advantage claimed for the new system:

"(1) It will facilitate the working, under favorable conditions, of coal-deposits for local markets by miners without large capital, as no land-purchase money would be required, and the small royalties charged would be paid out of the earnings; (2) it will facilitate larger operations, as the leases could be made sufficiently liberal in the matter of time, area, and other conditions, to induce

healthy competition and meet all real demands; and yet in all cases the general supervision of the Government could be such as to (3) *prevent waste in the extraction and handling of these fuels;* (4) the system can be operated in such manner as to prevent the evils of monopolistic control; (5) *that it will permit the Government to reserve from general use fuels especially suitable for metallurgical and other special industries; and* (6) *it will enable the Government to protect the public against unreasonable and discriminating charges for fuel supplies.*"

From the above quotation it can be realized what interests are at stake when the question of fuel preservation is viewed from beyond the national horizon. It is hoped, therefore, that this presentation of foreign achievements, so long as they aim to clarify and amplify the understanding, among industrial circles, of fuel commodities and conversion, will be welcome to American readers. Also, that the book may serve to increase the general public interest in the matter, and that it may help to raise the special branch of gas-power engineering to the high level of excellence associated with the general industry in America.

A few words may be added on the author's conception of the gas-power problem and its treatment in the book.

Regarding gas producers, I believe that there is at present altogether too much importance affixed to the employment as fuels of such high-grade materials as anthracite and coke, and that gas producers burning this class of coals represent merely a transient phase in the ultimate development, and are applicable and capable of competition with existing steam and hydro-electric power plants in the smaller sizes only.

Advocating as we do nothing less than the complete abandoning under certain conditions of a traditional and wasteful but universally adopted and reliable method of power generation such as steam in favor of a novel system, it is essential that the savings which we guarantee be large enough, lest they will not appeal to the American investor. Thus we must add to the high efficiency of conversion of the kinetic coal energy into work the greater economy of using inferior and cheap grades of coal and such as hitherto escaped utilization entirely.

The discussion of gas producers is, therefore, limited to such types as are capable of burning lignite, peat, low-grade bituminous coal, mine culm, and other waste. Nor has the attempt been

made to enlarge on the theory of design and construction of these apparatus, since what could be offered at the present state of our knowledge would be mere *speculative* theory, not based on adequate experimentation and data.

Regarding gas engines, the underlying tendency is not merely to dwell upon the now undisputed thermal superiority of gas prime movers over other modes of generation, and to evince that their mechanical and commercial prospects, under certain conditions, are unrivaled, especially when waste gases are available. My aim is rather to take the reader through all the different departments of those industries in which power is a controlling factor, and to ascertain by logical analysis that the ultimate success of this new claimant lies — besides in its adaptation to a few special services such as blowing, pumping, rolling and the propulsion of vessels — with the concentration of large power units in the central station, where all the weakness of the gas engine can be most effectively counteracted and its good points fully secured. The utilization of waste gases and other low-grade fuels in gas-engine-driven central stations offers, I believe, the only means, at the present time, for securing such high and lasting economies as are essential in order to enable electric drive all over the works, with its resulting advantages, to be adopted, at the same time liberating additional powers for profitable outside distribution among neighboring industrial districts.

The great number of excellent drawings which serve to substantiate the statements advanced in the text, and for which I am indebted to the executive engineering circles of the German industry, will prove, I hope, a very effective help to all those whose interests demand an intimate knowledge of the details of design. All important results from the experiments of European engineers and scientists, and all other data of value, have been recalculated for the English system, and both metric and English units are given so as to facilitate a comparison and make the figures more universally applicable.

The large amount of computation and numerical work involved makes it unlikely that the book is free from errors, and I will gratefully acknowledge notice of any errors or discrepancies.

In conclusion I desire to express my appreciation and thanks to the following engineers who have either contributed to the work, or have rendered me helpful assistance in some other way:

Prof. H. Diederichs, Cornell University; Dr. C. E. Lucke, Columbia University; Prof. R. H. Fernald, Washington University; Prof. A. J. Wood, Pennsylvania State College; Mr. C. P. Poole, New York; Mr. H. Freyn, Chicago; Mr. C. G. Atwater, New York; Mr. E. A. Uehling, New York; Monsieur R. E. Mathot, Brussels, Belgium; Herr Ernst Neuberg, Berlin; and Herr G. H. Davin, Nürnberg, Germany.

Acknowledgment is also due to the Verein Deutscher Ingenieure, and to the United Engineering Societies, of America; further, to the *Iron Age, Power,* the *Engineering and Mining Journal,* the *Iron Trade Review* and *Cassier's Magazine* for the courtesy of permitting the use of those papers and articles which I have read or contributed to them for publication previous to their use in this book.

F. E. Junge.

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PART I

THE EVOLUTION OF GAS POWER

I

GENERAL ECONOMIC ASPECTS OF THE PROBLEM

Methods and means of conserving and protecting the natural resources of a country, or the products gained from their transformation, are as important for establishing and maintaining commercial superiority as are the ways and processes of acquiring them. Therefore, economy has become a potential factor in the industrial pursuits of our age, and efficiency the guiding principle of energy utilization, regardless of whatever special form the latter may assume.

Of the mineral and metallic ores which constitute the natural wealth of a country, it is primarily coal and iron which deserve our foremost and careful attention, since present public utilities and comforts are absolutely founded on the permanency of their supply. To show how intimately the different countries are interested in the output of one of these factors — and one which is justly regarded as indicating the condition of national prosperity — it may be mentioned that of the world's total production of iron in 1905, which amounted to 54,000,783 tons, the three countries which at present march at the head of industrialism, namely, the United States, Germany, and England, produced together 81 per cent., the United States alone 43.2 per cent. of the total output, which owing to an unparalleled inland demand was almost all consumed in the home market.

It is known that the consumption of coal bears a direct but ever increasing relation to the production of iron and steel, and that an increase in the output of our metallic products must inevitably bring about a decrease of the fuel resources. This fact is of consequence for the economics even of a rich country like America, not so much on account of an impending depletion of the coal fields, but on account of the extreme value they possess for future industrial activities. It may be objected that the sources of fuel supply have not yet been accurately measured up the world over, and that the centers of production may in times

to come be found in countries that are now quite undistinguished in industrial annals, and which may, perhaps, pass beyond our control entirely. Yet this objection does not bear sufficient justification to promote the continuance of wasteful production. For it is quite certain that America, owing to its abundant and comparatively virgin resources, will sooner or later become an important *seller* of coal to the older European countries, which are becoming rapidly impoverished since the growing shrinkage of their remaining store cannot keep pace with the rising demand for very long.

That the economic utilization of our irreplaceable fuel resources is of greatest importance also to present industrial pursuits can best be realized when recalling the fact that the world's total annual coal production and consumption has increased since the time of the invention of the steam engine, that is, within 125 years, to about fifty times its original value, while until a short while ago not more than 5 per cent. of its total energy was usefully employed for the generation of heat, light, and power in the various industries. It is only within the last 10 years that the conditions of power production were brought to a high level of economic excellence. Taking a concrete case:

The United States Census Office has now reported regarding the development of power used in the manufacturing industries in the United States. In 1870 the total power employed in the country was 2,346,000 h.p.; in 10 years it had increased 45 per cent. to 3,411,000 h.p.; by 1890 it had advanced 75 per cent. to 5,955,000; by the end of the century it was 10,410,000, a further increase of 75 per cent.; last year the aggregate was 14,465,000, or an advance of 39 per cent. Should the rise continue during the next few years at the same rate the increase for the present decade will be no less than 93 per cent. Before 1890 the main sources of power were steam and water, but since that time gas and electric power have made enormous strides, the advance from 1890 to 1900 amounting to 1400 per cent. in the case of gas, and very nearly 2000 per cent. in the case of electric power. Electric power totals 1,138,000 h.p., the remainder being divided between gas and miscellaneous power. It is interesting to note that 35 years ago water power accounted for nearly one-half of the total, while now it is represented by 11.5 per cent. The total gas-engine horse-power employed was 289,514 in 1905, 134,742

in 1900, and 8930 in 1890. The percentage of increase from 1900 to 1905 was 114.9, only second, as regards increase, to water power. But, of course, steam leads by a long head. The return for 1905 was 10,664,560 horse-power.

The total amount of coal consumed in United States manufactures for purposes of power generation runs up to almost 100,000,000 tons per year, representing about 25 per cent. of the total annual coal production. Figuring at an average price of $2 per ton, it is obvious that the universal adoption of a method of generation which will render an equivalent power service at one-half the consumption will represent an annual saving, in treasure, of some $100,000,000, disregarding entirely what the saving in fuel means to future generations.

Recent comparative researches made, among others, by such competent and impartial bodies as the United States Geological Survey, and undertaken with a view of demonstrating to the public the great practical possibilities of securing higher efficiencies in the use of fuels, have evidenced the fact that the average bituminous coals, as well as the lignite and peat fuels tested, will yield in gas producers from 2.4 to 3 times the amount of power they have given under steam boilers of equivalent capacity. And what is even more important: That certain low-grade coals which could not be burnt under boilers at all are susceptible of utilization by converting them, through direct gasification in producers, into useful work.

With these undeniable results in mind, it is evident that the evolution of gas power has brought about ideal as well as practical advantages. An ideal one is that the kinetic capacity of our fuel resources has been more than doubled, and the practical ones are that materials and property which were hitherto deemed utterly worthless have enormously increased in immediate value. A number of other achievements which can be traced as resulting from the application of this new mode of generation are as follows: Vast districts which precluded the development of industries owing to the scarcity and cost of fuels have been opened to the invasion of capital and commerce. Large-scale production and long-distance transmission of energy over wide territories have been rendered more profitable. The electrification of railways has been hastened through the liberation of new, bountiful, and cheap sources of motive power. The exclusive adoption of pure

electric drive all over the works has been made possible by economic concentration, that is, through the generation of electric current in large gas-engine-driven central stations. The radius of action of all power-driven vehicles and self-propelled crafts has been extended to almost three times its former value. The damage done by the direct burning of coal, through smoke and the destruction of valuable by-products, has been obviated and a new and vigorous development of our chemical industries has been stimulated. Finally, the agricultural capabilities of our soil have, by the provision of an ample supply of nitrogenous manure gained through the gasification of coal (sulphate of ammonia), been brought in accord with the ever growing population. And last but not least, the small or private user of power has grown more independent of the large corporations and municipal-supply undertakings, since the evolution of gas power has put both the small and the large producer on the same level of excellence as regards efficiency of output.

While it is impossible to estimate the monetary value of the benefit which will accrue to industry in general from these performances, it can be taken that the gain so far effected in some manufacturing pursuits will amount, when the saving in self cost is only 1 per cent., to an increase of 10 per cent. and more in net profits, secured from the sale of the finished goods. In the iron industry, for instance, the application of gas power has reduced the price per ton of pig iron smelted by from 50 cents to $1.25, and that of the finished products by $3 and $4 per ton according to locality. This remarkable decrease in cost of production will enable all branches of manufacture to provide, from the larger margins of profit available, greater reserve funds, which in turn will help them to keep abreast of the times and also to tide over periods of business depression, thereby tending toward the stability of modern industry.

Since all revolutions in the development of human activities in order to be successful must occur at a time when conditions are ripe for such innovation, a radical change in power-producing methods could come to a commercially prosperous issue only when evolving from necessity. The very abundance of natural resources in this country must therefore be regarded as the principal cause why our subject has not appealed more strongly to American industrial circles before this, while the rising scarcity

and cost of fuels have forced European engineers to concentrate their executive energies earlier toward more economic methods in the field of power generation. In order to give an approximate idea of what so far has been done in the United States, it may be taken that there are to-day in operation or on order in this country an aggregate of some 260,000 h.p. in large gas engines, most of which are running on natural gas. Among them are units directly coupled with 4000-kw. alternators. Of the total number there are to be employed in the iron and coal industries alone 150,000 h.p. If we estimate the amount of energy that can be made available by the utilization of blast-furnace and coke-oven gases in modern steam plants at approximately 2,500,000 h.p., then the application of gas power will give an addition of at least 2,000,000 h.p. which would otherwise be utterly wasted, Of the total amount of energy which becomes thus available, namely 4,500,000, h.p., the present generating capacity represents only 3.3 per cent., so that there is an enormous field of activity before us. Yet if we consider that the world's total output in gas power has increased since 1902, that is, in four years, in a ratio of 1 to 6, namely, from 181,000 h.p. generated in 327 gas engines, to 1,000,000 h.p. produced in 1000 large gas engines, of which one-half are "made in Germany," one-fourth in the United States, and the rest in Belgium, England, France, etc., then we must agree that the evolution of gas power marks, indeed, a development of unprecedented rapidity of one of the most difficult motors that has ever been conceived in the history of mechanical engineering.

Engineers who have as yet hesitated to abandon traditional methods of power generation on account of the fresh investment required to bring their plants up to modern demands should remember that within the past 26 years, which represent an era of unparalleled industrial development, 50 per cent. of the world's capital has been destroyed through the supersedure of apparatus still in working order, but no longer profitable. And they should bear in mind that no small part of the enormous fortunes which have been aggregated by the captains of industry in this country were gained through the courage and readiness with which they discarded inferior apparatus *before* their competitors would realize that what Andrew Carnegie has termed "depreciation due to the advance of the art," or the destruction of fixed capital, is more

than compensated by the prompt instalment of improved machinery.

Wisdom and prudence will seize this time as the very best for introducing such sure and lasting economies as will make their possessors secure of a competence and a profitable business, however lean may be some of the years to come.

II

HISTORICAL AND ANALYTICAL STUDY OF THE DEVELOPMENT AND CRITICISM OF THE PRESENT MODE OF APPLICATION OF GAS POWER

It is evident that the conservation of the world's natural resources, both by economic methods of production and by scientific means of transformation, tends toward the stability of modern industry and is essential to the life and prosperity of future generations.

Great savings in the world's supply of fuel materials cannot be made unless recourse is had to the elimination of traditional methods of production which have largely stood in the way of economical progress, and to the adoption of novel means of generation which effect the transformation of fuel energy into mechanical power in a more direct and efficient way. To the achievements already realized in this direction, there has lately been added one that even a few years ago would have been deprecated by the conservative engineer as a more or less fantastic and impossible dream, namely, the gasification of inferior grades of fuel, the utilization of waste products, and their direct conversion into useful power in gas engines.

Who can help admitting that the employment of gas power has actually become a factor of consequence in the world's total energy output when it is considered that in Germany, a small country of four-fifths the size of Texas, there are to-day in the iron and coal industry alone, in active service or in contemplation, 136 gas blowing engines with 161,300 h.p., 200 gas dynamos with 206,300 h.p., 11 gas-engine roll drives with 17,000 h.p., and 47 coke-oven dynamos with 40,000 h.p., besides 4 engines with 1500 h.p., for other purposes, or a total of about 400 large gas engines with a combined capacity of 420,000 horse-power.

As in the case of every other technical innovation the early period of growth of a novel method of energy making must needs be sporadic and must encounter competition in order to gain strength together with progressing expansion. Isolated inven-

tions, even if commercially sound, will fail unless technical science and the development of appliances are correspondingly advanced.

Gas Engines

The Diesel engine stands as an example of this fact. Conceived some 20 years ago, it was not made a commercial machine until quite recently. The difficulties in finding suitable materials that would stand the enormously high temperature and pressure stresses, the absence of automatic machinery and other facilities which would allow its manufacture to be put on a commercial footing, the impossibility of finding among the rank and file of engineers a sufficient number of men that could be trained to attend the new engines successfully — all these things proved obstacles in the path of the industrial adoption of this new invention. We were all convinced at the time that it marked a truly wonderful link in the chain of energy transformation, despite the fact that the theoretical predictions of the inventor were not borne out in later practice.

A similar experience was true of the Brayton engine, of which we find mention in Dr. Lucke's "The Heat Engine Problem." [1] Without indulging in visionary prophecies, it may be said that the working process of this engine is bound to find more general recognition in future practice if the ideal, which we are striving after in gas-engine engineering, is to be realized, namely, "regulable and enforced combustion of a precompressed dynamic medium of air and fuel in quantities determined by the cut-off from the engine governor according to the load," or speaking in terms of the cycle: "a process composed of adiabatic compression, heat influx at constant maximum pressure, adiabatic expansion, and heat efflux at constant atmospheric pressure." But Brayton was hopelessly ahead of his time, and glancing over the discussion which followed the reading of the paper mentioned, it will be found that even Brayton's distinguished interpreter was not understood. And it is likely that even to-day there are but few competent observers who will admit that there is salvation beyond the present standard design.

This presentation, however, could not be complete if reference were not made to the probable future development of gas prime

[1] *Transactions* Am. Soc. Mech. Engineers, Vol. XXIII, p. 202.

movers. For the ideal process of continuous combustion, it matters not whether the fuel burnt is gaseous or liquid, the distinction being a mere incidental and external one. With every internal-combustion engine the goal is the unstraining of gas from a higher to a lower tension, preferably down to the limit of atmospheric equilibrium. All present types of gas, oil, gasolene, and alcohol engines are included under this designation. They also are continuous-combustion engines in a certain sense, though this feature is an unsought for and undesirable phenomenon

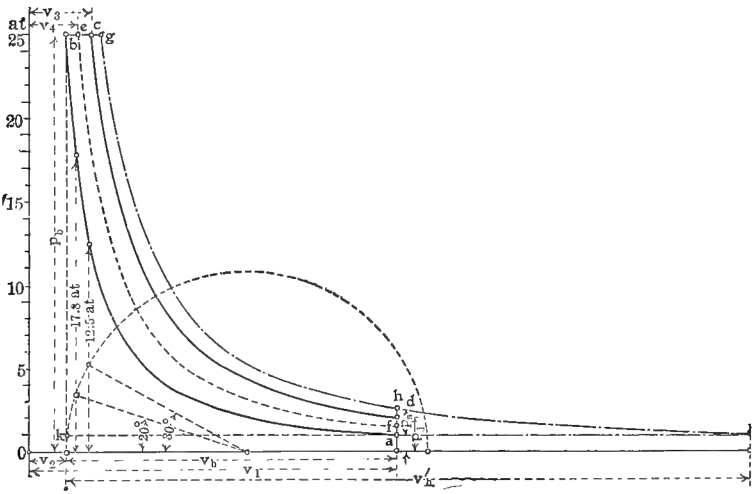


FIG. 1. — Theoretical Working Cycle of Diesel Engine.

accompanying the peculiar working process. The term "explosion" is incorrect when applied in this connection.

In order to bring about combustion it is necessary that air and fuel should be introduced in correct proportions under similar cyclic conditions during the entire range of load. Further, the two constituents must be perfectly mixed when entering the cylinder, in order that each fuel molecule may find its corresponding quantity of oxygen which is necessary to support combustion. Finally, since combustion of the charge particles causes a rise in internal pressure, while the initial piston stroke tends toward its reduction, the rapidity of heat influx must bear a certain fixed relation to the piston speed, in order that the two counteracting influences may be equalized and continuous combustion at constant pressure be secured. In the Diesel engine, of which Fig. 1

shows the theoretical working cycle, none of the above conditions is brought about. We have a constant body of air to support combustion, a pressure of the injected oil vapor which does not bear a fixed relation to the varying internal pressures, and, therefore, a speed of fuel influx which is irregular and one which in no way corresponds to the piston speed of that period. Nor does each fuel molecule on entering the cylinder find at once its corresponding quantity of oxygen. This feature retards ignition and flame propagation and makes the combustion a seemingly continuous one, though what we actually see is after-burning.

It was only after long and costly experiments with various forms of inlet nozzles that an artificial retardation of heat influx was finally obtained and the desired pressure balance secured. Yet to the casual observer, the Diesel engine appears to be representative of the continuous-combustion type. Notwithstanding these deficiencies, the thermal results of the engine are so excellent that it is truly indicative of what we may expect on a further approach to the ideal process.

Attention is called to an essay by Carl Weidmann, D.E., of the Technische Hochschule, Aix la Chapelle, Germany, on the enforced regulation of combustion in heat engines. In this he describes his new engine, designed with a view of utilizing the experience gained with the Diesel engine. The Weidmann engine is similar to that of Diesel in that gasified fuel is injected into a highly compressed body of air in the working cylinder, with the remarkable difference, however, that a corresponding amount of air is introduced with the fuel by a receiver piston moving at a rate corresponding to the speed of the working piston. The fuel and the air are so intimately mixed that combustion must regularly occur. Fig. 2 gives a theoretical diagram of the proposed process, from which the inventor calculates a thermal efficiency of 50 per cent.

The engines of the Otto type, as constructed by leading manufacturers, have been developed to a state of high perfection. Their deficiencies and incidental phenomena have been so far eliminated that the enthusiastic advocate of gas power is apt to overlook them entirely. Yet of ten indicator cards taken under identical conditions from the same engine, every one will reveal its fundamental weakness, namely, the impossibility of controlling the combustion, which is the most important function of the

working process. The irregular and imperfect mixing of the charge constituents, the possibility of premature ignition and after-burning, are drawbacks of the present working cycle of gas engines. Of these Fig. 3 gives the diagrammatic representation.

Various attempts to improve on the working process as carried out in standard engines (as by prolonged expansion, compounding, and water injection) have proved to be entries on the wrong side of the balance sheet. The drawbacks common to all of these so-called improvements are increased bulk, weight, first cost, and negative work expanded. The best method of

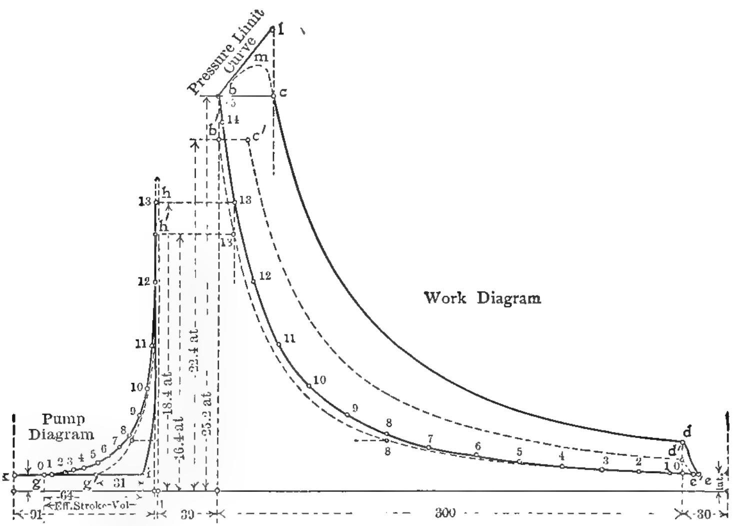


FIG. 2.—Theoretical Working Cycle of Continuous-combustion Engine (Weidmann).

prolonging expansion is by high compression of the dynamic charge before combustion. The most economical way of reducing heat losses through the exhaust is by utilizing the same for raising steam in an exhaust boiler. As high as 160 lb. per square inch can in this way be generated and used for factory heating or other purposes. Generally 10 per cent. or more of the total output can be recovered from the exhaust of gas engines. Even the interesting experiments of that distinguished authority, Mr. Dugald Clerk, in which he tried to improve on the working process by increasing the density of the charge before compression, have failed to effect any considerable advantage. The additional

neutral gas he used, though it reduces temperatures all around, tends to retard the influx of heat, and thereby promotes after-burning and heat loss through the exhaust. The combustion process pure and simple, as used in the standard types of engines (the Nuremberg, the Körting, the Oechelhäuser, the Cockerill,

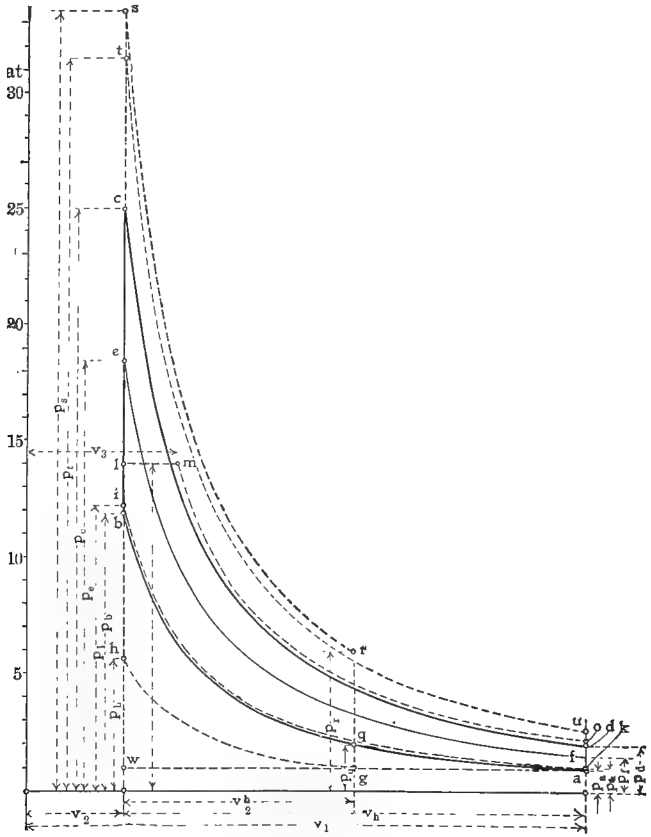


FIG. 3. — Theoretical Working Cycle of Otto Engine.

the Reichenbach, etc.), gives the highest economic efficiency attainable with the Otto cycle.

Another practical drawback, and one that cannot be overcome by the highest engineering skill because inherent in the cycle, is the lack of overload capacity in gas engines and the fact that the range of economical load is limited to only a fraction of the total.

This is by no means as small as is usually held. Fig. 4 shows the rate curve of gas consumption of large blast-furnace engines of an earlier design as obtained on the continent from several years of actual practice. It is seen that the line of gas consumption per brake horse-power presents characteristics similar to those of the steam engine, rising from 100 to 130 cu. ft. when the load drops from full to 50 per cent. of the maximum. Another unfortunate characteristic of the gas engine is its lack of overload capacity. This often militates against its adoption and is especially felt when operating urban and interurban railway plants. It can be

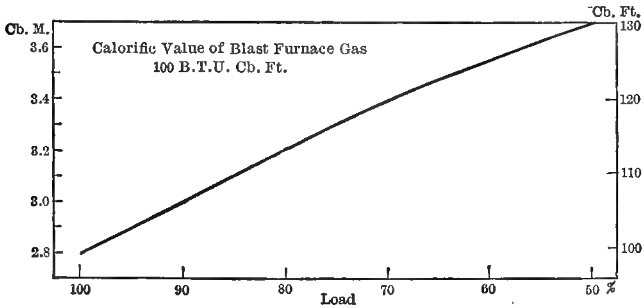


FIG. 4. — Gas Consumption of Old-type Blast-furnace Gas Engine at Various Loads (Germany).

compensated either by a storage battery of sufficient capacity, or by an auxiliary steam-turbine system as proposed by Stott, or by the installation of spare gas-engine units with a corresponding equipment for gas storage or instantaneous generation. There is no prime mover that lends itself better to the latter application, especially as since the employment of compressed air, and of electric starting motors, gas engines can be started quite as easily as steam engines.

Since the majority of failures of gas-power plants have been due to the fact that the engines selected were too small for the maximum duty which they were expected to perform, the rating of gas engines should be standardized and the public should be advised by the manufacturers that for a service with heavy overloads, such as occur, for instance, when driving rolling mills, the capacity of gas engines must be considerably larger than that of steam engines.

Though the ideal after which we are striving is still far from

what we have actually attained, it would be wrong to conclude that the present type of gas prime movers is not on a high level of excellence, not only as an economical but as a reliable machine. Just as the steam turbine cannot be regarded as having reached its highest state of perfection, and yet is a commercial engine of the greatest possibilities, so it is with the gas engine. After having passed out of the costly experimental state, and after having reached a condition of standard design, its manufacture, when properly directed, is now as profitable to the engine builder as its application is to the power consumer.

Figure 5 shows how improvements of design and construction

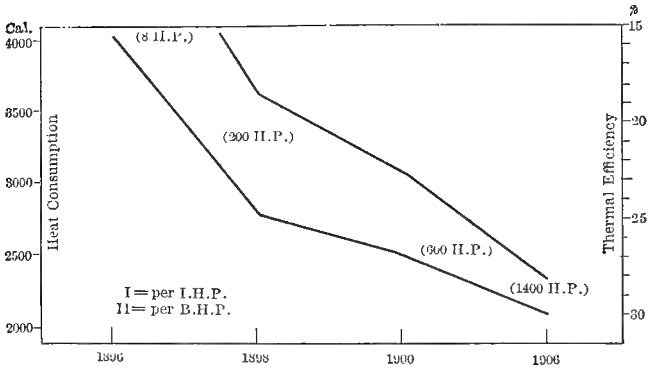


FIG. 5. — Table Showing Increasing Efficiency of Gas Engines within Ten Years (Belgium).

have gradually lowered the consumption of heat per unit output in gas engines.

The variety of earlier forms has now been reduced to two classes, (1) the double-acting tandem four-cycle engine, and (2) the double-acting two-cycle engine. The single-acting type of each is only applicable in the smaller sizes. Each type has its disadvantages and each its special field of application. The four-cycle is used for general power work and the two-cycle for blowing service, pumping, and wherever variable and low speeds are essential. There is a tendency toward the employment of higher speeds in large gas engines, in order to reduce the first cost also of the generator. Therefore, since the peculiar process of charging with an open exhaust limits the two-cycle engine to speeds of from 80 to 100 as a maximum, this type is at a disadvantage.

It would lend itself better to the building of vertical engines. Vertical engines promise great savings in manufacture and, of course, in floor space. They must be developed in order to compete with steam turbines in space economy, and also for purposes of ship propulsion.

Of the various methods of regulation applicable in large gas engines, namely, the quality, quantity, and combination system, the last named (as developed by Reichenbach and Mees) is superior to all, because it reduces the calorific value and the quantity, and therefore the compression of the mixture at the lower loads, less than do the others. Therefore, more regular and efficient combustion is secured with decreasing load and lean mixtures, especially when the point of ignition is automatically advanced.[1]

Regarding the latest thermal performances of internal-combustion engines, attention is called to, (1) a 14-h.p. Marienfelde alcohol motor and a 70-h.p. Diesel oil engine showing on test an indicated thermal efficiency of 41.7 per cent., (2) a 20-h.p. Güldner gas engine running on city gas with 42.7 per cent., and (3) a 500-h.p. Borsig-Oechelhäuser coke-oven gas engine with 38.6 per cent. These figures refer to approximately full-load conditions. Therefore, 1 h.p. indicated in the cylinder of the best gas engines so far on the market requires the expenditure of only 1490 calories or 5900 B.t.u., which corresponds to 7442 heat units supplied per brake-horse-power per hour. The economic efficiency of the latest types of gas engines, based on the actual output of available work, is, therefore, between the limits of 32 and 33 per cent.

Gas-power Economics

Engineers who either have antagonistic attitudes toward the above undeniable performances or are disinclined to adopt them, usually try to belittle their economic importance. They point out that in proportion to the relative value of the several elements which determine the commercial-economy coefficient of a heat-power plant, the factor of fuel expenditure is not the most important item of expense. They say, further, that it is often

[1] For detailed information on problems of design, refer to Dr. Lucke's "Gas Engine Design," to Güldner's "Design and Construction of Internal Combustion Engines" and to the author's treatise on "Design, Construction and Application of Large Gas Engines in Europe."

completely overborne by the fixed charges, especially by the interest on the initial cost of equipment, which is for gas still higher than for steam per horse-power output, though some manufacturers have succeeded in almost equalizing this difference. Yet it must be borne in mind that even so small a saving as 0.01 of a cent per horse-power-hour amounts, with a plant of 1000 h.p. output and 3000 working hours, annually, to a total of $300 a year. Figuring on 10 per cent. amortization, the improved machinery which effects this saving may cost $2000 more and will yet give a net annual saving of $100. Since the reduction of gas consumption by the adoption of gas engines in place of gas-fired boilers and steam engines is generally in the proportion of 2 to 1, and often as much as 3 to 1, depending on the standard of comparison, the factor of fuel cost is by no means a negligible quantity in the horse-power-hour calculation. This is especially true where power is directly needed, and, with low gas economy, recourse must be had to costly boiler coal, as is the case in iron-smelting plants and collieries. The savings effected by the installation of cheaper turbo-dynamos do not offer anything near an adequate compensation for the increased expenditure in plant fuel cost.

In large power plants the item of fuel cost is composed of, besides the price for the coal, the expense of handling it between the car and the ash pile, including sufficient fuel storage capacity to guarantee permanence of production during all emergencies, and especially against interruptions in the supply service, such as are occasioned by strikes, railroad accidents, car or locomotive famines, etc. It is obvious that with the reduction of the fuel bill to one-third, the interest on the amount of capital locked up in the coal stored, and in the storage equipment, as well as the cost of operation and up-keep, is correspondingly reduced. With the same investment the gas-power plant can tide over periods of fuel shortage, and keep up production when the steam competitors would have to shut down.

The question of fuel valuation which comes up when studying the comparative cost of power plants and their economics has still another aspect to it. The present attitude is that the cheaper the fuel the less profitable it is to use gas power in a plant. If, therefore, a gas-power plant cannot effect a saving in the cost of labor, supplies, and repairs, over steam, a definite economic

limit will be reached which is determined by the price of fuel, and beyond which there is apparently no hope for gas power. Curves have been plotted showing diagrammatically the comparative cost of a gas and a steam installation. When first plotted they were equal for coal in the neighborhood of $2 per ton. A year later it was shown that the two cost lines crossed at a point corresponding to a value of coal of $1 per ton. It has been suggested that a further reduction in the price of gas-power machinery may eventually tend to effect a crossing of the two curves at the zero point of the cost of coal. This would mean that when fuel can be had for nothing, both plants can deliver power at the same cost.

In the iron and coal industries blast-furnace and coke-oven gases are available as a by-product and may be used for the generation of power. These gases were formerly wasted, either by inefficient methods of transformation or still earlier by blowing them into the air. They were, therefore, called waste gases and were marked in the columns of plant economics as having no commercial value whatsoever. It is now regarded as correct to appraise these gases at a rate, (1) corresponding to that of a certain weight of coal of thermal equivalence, (2) to the amount of steam that can be generated by a certain measure of both fuels, or (3) to that of some other standard depending on local conditions.

It is apparently a mistake to regard any kind of combustible matter as having no value. There are, of course, cases, especially in a new country with undeveloped fuel resources and desert districts, where that value is not immediate and practical, but speculative and theoretical.

There is so much being said just now about the realization of ideals in industrial pursuits that it is surprising to find in the conservation of fuels no trace or effect of such doctrine. All power plants are designed with the ultimate object of being producers of wealth for the present owners and with no regard for future activities. But even when guided by purely material motives, it is well to remember that the valuation of property is subjected to great fluctuations brought about by the rapid expansion of industries and the development of new branches.

An iron-smelting plant having steam turbines and gas-fired boilers in the power station may at present consume all of its

available gas in the blast furnace and steel works. If a corresponding allotment for rolling mills is to be added, or if other industries are attracted to settle in the neighborhood, or if some community or city should build up in the immediate vicinity of the plant, to which it might be desirable to sell power at a profit, then the works management would be confronted by the necessity of either buying good steam coal, or else of consigning steam turbines and boilers to the scrap heap and of replacing them by gas engines able to generate the required additional energy from the available gases or other waste at no additional heat cost.

With the rapid spreading of industries at this time, it is wise to design power plants with a view to prospective rather than to immediate earnings. Therefore, comparisons of the cost of different types of plants are not only for the most part inaccurate, but are also of local and momentary value. Earning capacities depend on the market for the output. Markets commend the employment of the most economic methods of fuel transformation, utilization, and conservation, rather than the adoption of methods which appear to secure the maximum immediate profit.

This question of the economic relation of a gas to a steam plant has passed into an entirely new phase since it became possible to gasify directly such fuels as cannot be efficiently used for raising steam under boilers. This brings us to the other important factor in the evolution of gas power, namely, the producer, which has helped to conquer for the gas engine the enormous and practically unlimited field of application which it is just beginning to enjoy.

Gas Producers

The United States Geological Survey has been conducting a series of tests at St. Louis to ascertain how well suited the different grades of bituminous coal are for producer work; and also how the results compare with those obtained when firing these coals under steam boilers. A résumé of these tests was presented at the last annual meeting of the American Society of Mechanical Engineers by Professor Fernald. Among other things the interesting fact was developed that the fuel consumption of the steam plant increased comparatively much more rapidly with the poorer grades of coal. I do not know whether these tests have been continued and extended so as to include the examination of

still inferior fuels, such as cannot without difficulty be burnt under boilers. In Germany, there are three or four types of producers in operation which have been working successfully on such material as city refuse, culm banks, etc., containing often not over 20 per cent. of combustible matter, and yet doing continuous service in connection with gas engines.

If, therefore, gas-producer power plants using the higher grades of coal, such as anthracite and coke, have been able to compete with steam plants using inferior grades of bituminous coal, the situation is now completely changed in favor of the first claimant, since we have succeeded in making gas from such fuels as hitherto entirely escaped utilization.

The gas producer in its present form is a comparatively modern creation. Developed from the regenerative furnaces such as were employed, among others, by Siemens in the process of steel making, they found early attention in England and France. The names of Dowson and Dr. Mond must be mentioned among those who took an active part in the vigorous development of earlier forms. The latter is especially known as having evolved a producer-gas system suited to the utilization of low-grade bituminous coal with the recovery of by-products in form of sulphate of ammonia, which has found an extensive use as fertilizer in agricultural pursuits.

These earlier producers were of the pressure type. In them steam and air were blown through an incandescent fuel bed, and the gas thus generated was stored in a holder. Their sphere of application was considerably reduced by the invention of the suction producer, which was first developed by Benier in France, and by Körting in Germany. Its apparent advantage consists in that the gas-making apparatus is under suction instead of under pressure, since air and steam are drawn through the fuel bed by the aspirating action of the engine piston. No extra coal-fired boiler is required for raising steam. This performance is left to the sensible heat of the gases leaving the producer. The bulky gas holder is also eliminated.

Suction-gas plants are, therefore, very simple, safe, and reliable in action, and have found an extensive field of adoption in Europe and also a limited sphere of usefulness in this country. The lower grades of American fuels present characteristics less suitable for gasification than are possessed by the European coals.

It cannot be said that the gasification of caking coal is a commercial proposition. In Europe there is no lower limit in grade of fuels. At the same time another and no less important problem has been solved, namely, the cleaning of the gas from tar and other impurities which are formed during the transformation process. This is done by converting the tarry products into fixed gases in the producer proper, either by blowing or drawing the unstable volatiles through the principal or through a second zone of combustion, where they are transformed into stable constituents which do not separate from the gas when being cooled. No complex and bulky cleaning apparatus is required, except an ordinary wet coke scrubber and means for drying. The question of tar extraction and disposal is thereby effectually solved and the gas is enriched accordingly.

Regarding the general design and the constructive principles of gas producers, we cannot refer to a condition of standardization such as obtains with gas engines. This would be true even if fuel characteristics were identical all over the world, since there is as yet no accurate knowledge even of the most fundamental features, as, for instance, form and dimensions of producer chamber, kind of grate, material for firebrick lining, water cooling of producer walls, size and location of gas flues, manner of air admission, rate of gasification, depth of fire, stationary or revolving ash table, effect of automatic feed, internal or external boilers. In short, it may be said that almost everything in the design is done by traditional methods not based on adequate experimentation and data. Of course, there are three or four different systems solving some of these problems in a fairly satisfactory manner, but there is little scientific knowledge available as to which of these is the most efficient. This is one of the many cases where technical practice goes its own and independent path toward an economic aim, neither aided nor obstructed by scientific knowledge, which can only construe a theory on the basis of experiments made on the new and successful machine after the same has been completed.

Some of the above problems have recently been solved to a certain extent for European fuels. Thus it was found advantageous for the lower grades of bituminous coal to make the producer proper of cast iron with water-cooled walls. This eliminates clinkering entirely. The cooling effect of the water does not

extend very far internally, but affects only the layers located at the extreme outside. The influence on the combustion process is, therefore, inconsiderable with large producers. Further, it has been found that the continuously revolving ash table was wasteful in consumption. Too much coal passed through unburnt, and the agitation disturbed the quiet action of the fire by constantly breaking up the numerous small gas passages in the fuel bed. Finally, it was found advantageous to have some control, preferably automatic, of the blast or of the suction pressure effecting gasification in order to be able to reduce or to increase the rate according to the condition of the fire or the load on the engine or station. In experimenting on this latter condition, it was found advantageous to insert between gas engine and producer a fan the speed of which is automatically varied according to the engine or station load. This increases greatly the elasticity of the plant, making the producer capable of carrying heavy and lasting overloads without affecting the engine. At the same time it eliminates spare producer units, gas holders, pressure regulators, pulsometers, and other cumbersome and expensive apparatus, and keeps the supply of gas steady and of more uniform quality.

The possibility of increasing the rate of gasification by means separate from the engine, as by induced draft, should be carefully investigated since it affords the desired means of reducing the cost of equipment, at the same time increasing the flexibility. Fortunately, the gas producer possesses in a marked degree the desirable feature of overload capacity, which the gas engine lacks.

The gas holder is one of the appliances that can be replaced by superior arrangements. As an apparatus for improving on the quality and uniformity of the gas by promoting diffusion and separating out the water molecules, it connot be regarded as adequate, exposing, as it does, a large volume of gas to the varying and uncertain atmospheric influences of the season. As a storage tank for meeting fluctuations of load and peak loads of long duration, its value is problematical unless made very large, especially for the weak power gases. To keep a 500-h.p. engine running for 25 minutes the holder must have a capacity of 20,000 cu. ft. Long gas mains of ample section are a sufficient reserve for equalizing the pressure at short periods of fluctuations. In ordinary suction-producer practice it is obvious that the large

volume of gas between engine and producer reduces the suction effect of the former and the sharpness of the draft through the fire. There is a general and commendable tendency apparent among German builders to disburden the engine of the negative suction work, and to deliver air and gas by means of fans in fixed proportions and under pressure into the working cylinder, thereby eliminating at once all incidental phenomena affecting regulation, such as are caused by fluid friction, inertia of the gas streams, undulatory fluctuations in the admission pipes, etc., at the same time increasing the capacity of the engine and the regularity and efficiency of operation.

For operating gas engines on board ship, producers must have means for keeping up the temperature in the producer while the engine is running at slow speeds or stopping, since otherwise it will not start up again on account of lack of suitable gas. This can be readily obtained by keeping up the rate of gasification through the exhausting fan and returning the gas into the producer where it is consumed again, there being practically no loss but that of the sensible heat of the gas radiating through the piping and, of course, the power required for driving the fan.

No producer can be regarded as up to date that does not embody means of automatically adjusting the amount of water or steam admitted together with the air into the fire bed in fixed proportions according to the load, since without this arrangement the fire will grow dead at the lower loads and the engine will not be able to pull up to a higher load again when necessary.

There are a great many questions that are yet unsettled, and await solution in producer theory and practice, and it is gratifying to know that the American Society of Mechanical Engineers has taken active steps toward thoroughly investigating the matter by a committee.

While the ordinary anthracite and coke producers show a general similarity at least in type, the bituminous-coal producers, and such as burn lignite and peat, offer a striking variety of forms. We have some taking air in from below the grate, or from its circumference, or from a central pipe, and others having the fire on top and taking air from above. Still others have two fires and take air from both sides. With the double-zone producer as developed by Fichet and Heurty in France, and by

the Deutz Motor Works and by Körting Brothers in Germany, lignite and peat is the most desirable fuel to use, especially in the form of briquets. The raw fuels may also be burnt provided that they do not contain over 20 per cent. of water, since otherwise the upper zone of combustion is apt gradually to wander down and therefore a second grate has to be inserted. However, lignite and peat containing excessive moisture are of little importance beyond the field of their production on account of the high cost of transportation.

The double-combustion process in itself is very simple. In the upper layers the coal is transformed to coke, the unstable

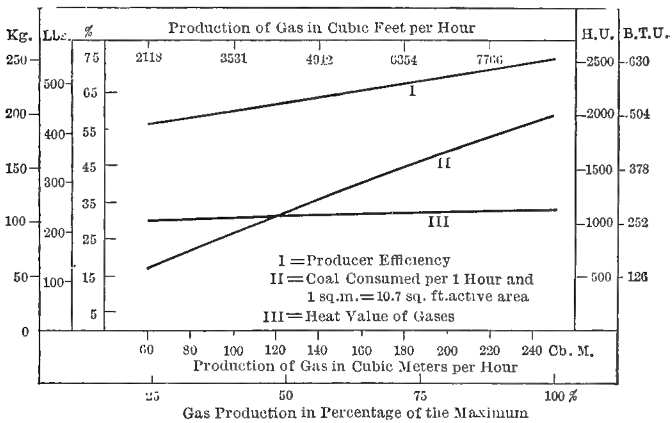


FIG. 6. — Performance of Deutz Double-zone Lignite Producer.

gases being discharged through the incandescent zone where they are transformed to fixed gases. The coke thus formed is burnt up in the lower fire after it has been extinguished for some time in the middle zone on its way downward. The gases formed below are, of course, stable and are drawn off together with those from above.

While the average consumption of anthracite and coke producers is about 1 lb. per brake horse-power-hour and usually less, Fig. 6 shows the performance of a Deutz double-zone producer burning lignite as fuel. It is seen that the efficiency of the process drops from 75 per cent. at full load to 63 per cent. at half load. This is not a very good performance for a producer, generally speaking, since with superior fuels up to 85 per cent. efficiency can be

attained. But it is of greater importance for the regularity of running that the composition of the gas remains practically constant at all loads as is indicated by the curve. The economic results of these plants are excellent. An 80-h.p. plant using Bohemian lignite of 9200 B.t.u. lb. consumed on test 1.19 lb. per horse-power-hour, corresponding to a heat consumption of 1100 B.t.u., and to a price of one-eighth of a cent per horse-power-hour in the particular location. (Meissen.)

It is, of course, impossible to state cost prices of such fuels as are adaptable to this type of producer and to consider them as correct and acceptable everywhere, since conditions of production and transportation must necessarily differ in different localities. To give an approximate idea of what obtains in the greater part of Germany, where in the neighborhood of 7000 h.p. are generated in lignite producers alone, it may be said that 50,000,000 tons of lignite were produced in 1905 and it seems that the stability of inland production will continue for a long time to come, disregarding entirely the importation of Bohemian coals. Since the price of average good gas coke is about three times higher than that of lignite briquets, its heating value being only about 1½ times higher, the cost per unit power in producer-gas engines is from 40 to 50 per cent. lower when using lignite briquets than when burning coke. The difference may be even greater in certain localities depending on the respective freight charges. We need only to glance at the map published by the United States Geological Survey,[1] showing the distribution of lignite and peat fuels in this country, in order to become aware of the impending revolution in power-producing methods and of the influence and the changes which it must have in the development of certain remote districts, notably in Dakota, Wyoming, and Texas.

The successful gasification of other low-grade combustibles, such as culm banks, is performed among others in the Jahns ring producer. It consists of a series of retort chambers containing the incandescent charge at different stages of the transformation process. Through these chambers the gas is drawn in succession. After the contents of one chamber have been completely gasified, it is separated from the rest, emptied, cleaned, and charged up

[1] "Report of the Operations of the Coal Testing Plant of the United States Geological Survey at the St. Louis Exposition, Part I. Field Work, Classification of Coals, Chemical Works."

again to enter the ring afterward as the youngest member. In the Von der Heydt coal mine at Saarbrücken, Germany, 2100 tons of culm are being gasified per month, giving out a total of 40,000,000 B.t.u.; in other words, 2.2 lb. of this waste generate 7140 B.t.u. in form of available gas. The gas is used for driving gas engines and firing boilers, and the plant has been in successful operation since 1903.[1]

Résumé of the Uses of Gas Power

Coming now to the third part of the subject, we shall briefly consider the application of gas power in modern industrial and other pursuits. Of all the various industries which have been benefited by the evolution of gas power, the iron industry has been the most favored, since the blast furnace as the potential source of energy not only serves to convert the raw materials into pig iron, but also produces gas as a valuable by-product. This can be used for producing the power that is required in the power plant proper, and besides leaves available a considerable surplus for other uses.

It is a well-known fact which need not be here developed in detail, that of the total quantity of gas generated in a blast-furnace plant about 50 per cent. is required within the plant. This includes losses at the furnace top and in pipings, namely, for driving blowing engines, heating blast stoves, operating the cleaning plant, and generating electric energy in the central station, while the rest, representing an amount equal to 25 h.p. per ton of pig iron produced every 24 hours, is available for outside purposes or sale. Modern combined works often possess their own collieries and coke-oven plants, which represent an additional source of available power.

In modern by-product ovens the quantity of gas produced depends on the quality of the coal coked, on its moisture and on the type of oven, and varies considerably in composition during one coking period. Deducting 60 per cent. for heating retorts and 10 per cent. for driving plant auxiliaries, there remain available for every ton of coal coked in 24 hours, from 5 to 6 h.p.

[1] For detailed information reference may be had to Samuel S. Wyer's "Producer Gas and Gas Producers." Also Mathot's "Modern Engines and Producers," Sexton's "Producer Gas," and the author's treatise on "The Utilization of Low-grade Fuels in Gas Producers."

for other uses. The third source of energy previously referred to, namely, the gasification of culm piles, will liberate from every ton of culm charged in the producer in 24 hours about 25 h.p., after deducting losses through deterioration, etc.[1]

That the total amount of useful power that can be gained by scientific transformation from the first two sources alone is no negligible quantity, will be seen when applying the above figures to American conditions. With an annual coke production of 35,000,000 tons in the United States, and utilization of the coke-oven gases in regenerative ovens, there can be liberated with modern gas engines in the neighborhood of 1,500,000 h.p., if a best consumption of 8000 B.t.u. per brake horse-power is assumed. With an annual pig-iron production of 25,000,000 tons the surplus blast-furnace gases will generate in the neighborhood of 3,000,000 h.p. in gas engines.

This large amount of surplus energy can, of course, be liberated only when gas power is employed for driving all machinery within the works. In small countries like Germany, England, and Belgium, the disposal of the available energy from iron-smelting plants and coal mines offers no difficulty, owing to the close concentration of industrial centers. The power is partly used for electric distribution to other works or mines which have no individual power plant of their own but only possess transformer substations. Part of the energy is sent to neighboring cities for lighting and other purposes. In the majority of cases it is found advantageous to distribute the surplus energy in the form of electric current rather than as gas, though this practice cannot be generalized. These large systems were installed originally to connect separated mines and works belonging to the same company or allied companies, and to equalize the power distribution by transmitting the surplus energy at one place to supply a deficiency at another. Such, for instance, is the case where the Stumm blast furnaces at Ueckingen send electric power to their ore mines, 37 km. distant, and where the Ilseder works furnish three-phase current at 10,000 volts to the Peiner rolling mills. In many cases plants are connected not so much to furnish each other with a regular supply, as to have a reserve for emergencies or accidents at one place or the other. It is very convenient for

[1] Refer to Chapter XI, "The Application of Gas Power in Coal-mining and Coke-producing Industries."

a new mine to have a supply of power available before it has its own coke ovens or generating plant.

A third application which the surplus power has found in Germany, and which recommends itself for adoption especially in this country, is to drive electric railways for the transportation of raw materials and finished goods throughout the commercial-distribution sphere of iron and steel works. It is obviously better for the ironmasters to get control of the transportation factor by building and driving their own railroads independently of the railroad companies.[1]

Technically considered, this problem is very attractive, since the particular application affords a nearly constant outlet for the surplus power all year round, because the production of iron and the consumption of energy are balancing each other. When depending on unstable outside markets, we always have to introduce into the calculation a coefficient of safety. With two blast furnaces, we can figure on the available surplus power of one furnace only as forming the basis for a guarantee to an outside consumer, since a fluctuation in the iron market may require the banking of one furnace; also the plant load factor of the proposed application becomes higher than when current is supplied to a neighboring city for lighting purposes.

We cannot leave this part of the subject without laying particular emphasis on the fact that the gases must be cooled, cleaned, and dried before being used for the production of power in gas engines. With blast-furnace gas the dust and the moisture must be eliminated not only when the gas is used in gas engines, but also, though to a less degree, when it is burnt under boilers or used for heating blast stoves, etc., since plant economy is thereby greatly increased. The cleaning apparatus giving highest all-around efficiency are the centrifugal high-speed type, such as the ordinary fan, and the Theisen washer. The power expended in cleaning the gas can be brought down to from 2.5 to 1 per cent. of the power obtained by the purified gas. The consumption of water varies from 6 to 9 gal. per 1000 cubic feet.[2]

It is difficult to obtain correct figures on the total savings that can be effected in the production of iron by the application

[1] Refer to paragraph "Gas Power for Electric Traction," Chapter XI.

[2] For detailed information reference may be had to the paragraphs on "Gas Power Economics," and on "The Cleaning of Blast-furnace Gas," chapter X in this book.

of gas power, but from 50 cents to $1 per ton of pig iron made have been recorded in various continental works, and from $3 to $4 per ton of finished goods turned out.

In central electric stations which are located where no energy is available from near-by iron-smelting plants or coal mines, the gas producer takes the place of the blast furnace and coke oven as the potential source of energy. Especially is the production of electric power at reasonable rates of importance for very large cities where the price of real estate in the centers of districts is high, and for isolated communities, country houses, and farms which are located outside the commercial radius of metropolitan or other central stations. The distribution of town gas for individual power purposes, while not so much restricted to central location within the city, cannot, without loss, be extended over wide territories. Moreover, at the present price of illuminating gas, it cannot compete in the field of power production with the independent suction-gas plant, even if the latter use such high-grade fuels as anthracite and coke.

Suction plants will work in the smallest sizes as economically as in the larger, and, of course, vastly more so than the largest and best equipped steam plants. They occupy very little space and may be installed in the basement of apartment and other houses without being at all dangerous or difficult to handle. Naturally the attendant must possess a degree of intelligence and training similar to one running a steam engine, though besides removing the ashes once a day his occupation consists only in filling the hopper with fresh fuel once or twice every two hours. The rest of the plant is self-regulating and needs no attention. Starting from cold does not require more than from 10 to 15 minutes. The smoke nuisance, which is sometimes so objectionable in cities, is completely eliminated for all grades of coal that can be gasified. The personal equation is greatly reduced, since the process of gasification is not dependent on the skill of the fireman. Stand-by losses are also very low compared to steam plants. For small work and very intermittent working, oil and alcohol engines are superior, since with them fuel consumption stops entirely as soon as the engine is shut down.

Speaking more particularly of the generation of power from illuminating gas, Fig. 7 shows the increase of the number of horse-power delivered from city gas works, of the number of illuminat-

ing-gas engines operated, and of the medium capacity of these engines in percentage of the figures obtained each previous year, all data referring to the performances recorded in Germany. During the 20 years for which data are available, the number of illuminating-gas engines has increased more than sevenfold, the number of mean horse-power generated having grown in proportion from 1 to 18.

The price for town gas has been gradually reduced during this period, the range being represented by the two extreme limits $1.77 and 60 cents per 1000 cu. ft. in 1881 and 1901, respectively. The economy of the illuminating-gas engine has in the meantime been increased in a measure represented by curves Fig. 8, which

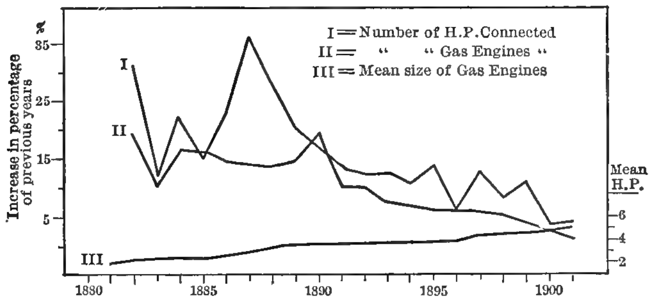


Fig. 7. — Table Showing Increasing Application of Gas Power from Illuminating Gas in 200 Cities (Germany).

show the comparative consumption of two 6-h.p. Körting gas engines, of which one was exhibited at the Karlsruhe Exposition in 1886, the other at the exhibition in Munich in 1898. Both tables together show how in the course of evolution the generation of power from city gas has grown more and more economical.

In order to analyze the influence of the electrical industry on the above performances, curves Fig. 9 have been plotted, showing the items corresponding to Fig. 7, namely, the increase in the number of electrical horse-power generated, in the number of electromotors employed, and in the mean capacity of these motors. A careful comparison of all the items bearing on the statistics of both gas and electric power application during the above period in Germany established the following conclusions:

(*a*) The mean capacity of gas and electromotors operated from central plants has continuously increased.

(*b*) The annual working time of gas engines compared to that of electromotors bears a ratio of 10 to 4; the amortization figured

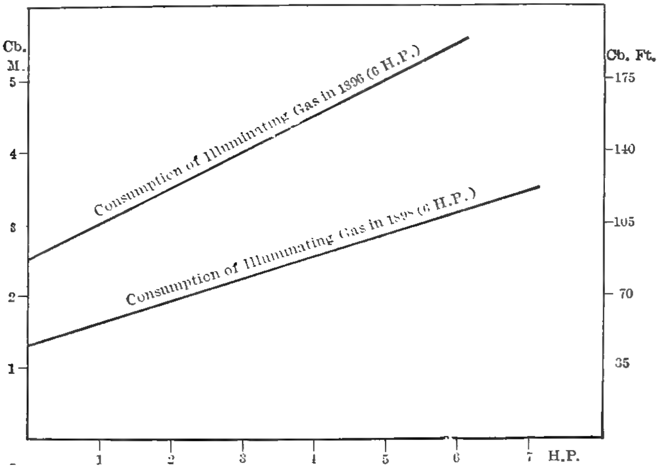


FIG. 8. — Comparative Gas Consumption of Körting Engines in 1886 and 1898 (Germany).

on the horse-power-hour of both is, therefore, approximately the same.

(*c*) The price of current from electric central stations for power purposes has remained practically the same from 1897 to 1901, but the price of illuminating gas for power purposes has been lowered.

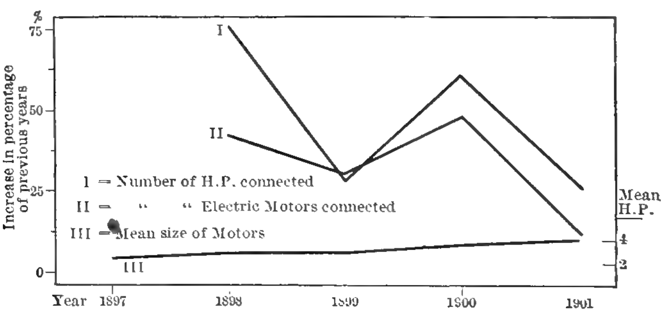


FIG. 9. — Table Showing Increasing Application of Electric Power from Central Stations in 100 Cities (Germany).

(*d*) The increase in the number of electromotors connected with public central stations is considerable, while that of the gas

engines is small, one of the main reasons being found in the introduction and growing application of the independent suction-gas plant. In order that the gas companies may not lose control of the situation entirely, they will have to reduce the price for illuminating power gas considerably.

(*e*) From the data at hand it is impossible to ascribe the fact of the small increase of the number of gas engines connected with city gas works to the influence of the growing central station business.

(*f*) The price per horse-power-hour from gas engines had in 1901 been reduced to about two-fifths of what it was in 1886.

A few words may be said on the results attained with independent suction-gas producers in the course of the last few years. In the central part of Berlin, where real estate prices and electricity supply conditions are very similar to those which obtain in New York, there are quite a number of independent suction-gas plants installed, serving to deliver electric energy to individual blocks. In Table 1, the operating results obtained from January, 1904, until April, 1905, in one of these independent block stations are shown. It is seen that the average continuous fuel consumption per kilowatt-hour is about 1¾ lb. of anthracite, corresponding to a price of a little more than half a cent. These results do certainly encourage further efforts toward independence from public central stations. But they may even be improved upon by using lignite briquets, with which a consumption of only 1.76 lb. per kilowatt-hour is guaranteed by German manufacturers.

TABLE 1

PERFORMANCE OF SUCTION-GAS PLANTS IN BERLIN (GERMANY)

BLOCK	KW. HOURS RENDERED	COAL CONSUMED LB.	COAL CONSUMED PER KW. HOUR LB.	TOTAL COAL CONSUMPTION LB.	OIL CONSUMED PER KW. HOUR GRAINS	COAL CONSUMED PER B.H.P. HOUR LB.
1	370,774	654,597	1.78	7,249	137	1.11
2	273,913	481,708	1.76	4,349	120	1.10
3	273,354	506,722	1.84	3,068	129	1.14
4	183,978	350,020	1.89	2,008	74	1.18

Figure 10 gives a comparison of the cost of power in over 220 towns and districts of England from the three sources, (1) public

electricity supply, (2) public gas supply, and (3) own suction-gas plant. It is seen that the number of places where the respective cost lines would cross or superimpose each other is exceedingly small, which means that in ninety-nine cases out of a hundred, it is more economical to install independent suction-gas power instead of using city-gas engines or electric motors, even when

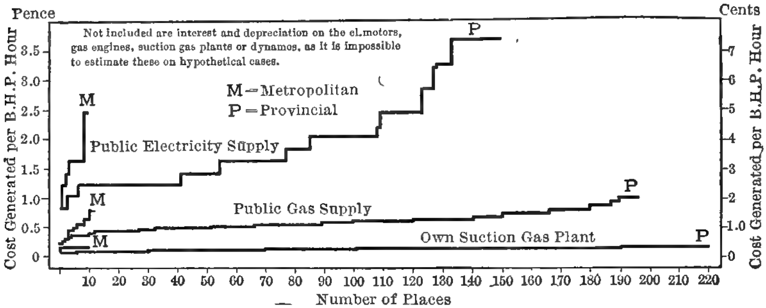


FIG. 10. — Diagram Showing Cost of Power in 222 Towns and Districts (England).

such high-class fuels as anthracite and coke are used, the amount of saving being represented by the ordinate distance of the respective curves.

In metropolitan and other pumping stations suction-gas power has been adopted with great success, the duty per pound of lignite briquets being 1,270,000 ft. lb. in Germany. Table

TABLE 2

PERFORMANCE OF SUCTION-GAS-DRIVEN PUMPING PLANTS (ENGLAND)

LOCATION OF PLANT	PUMP H.P.	HEAD IN FT.	COAL PER H.P. HOUR LB.
Welwyn Water Works	1.896	120	2.17
Paris-Plage "	13.9	137.6	1.68
East Kent "	13.64	255	1.3 coke
	12.96	330	1.28 coke

2 shows the results attained with some such plants in England.

The application of gas power by means of the portable gasolene engine on such farms where the cheapest forms of producing motion, namely, wind or water, are either not available or unreliable, and where steam power is too expensive and electrical

energy cannot be had, has filled a long-felt want. On the continent this form has been superseded by the alcohol motor, which is now to become a claimant for recognition in this country also. It would take too long to enumerate here the many farm machines which can now be operated by the adoption of gas power, accomplishing such operations as have made farm work drudgery for years. The stockman, the fruit grower, the thresher, the mill owner, will readily testify to the comforts and savings which the evolution of this new power has bestowed upon them. Yet we are only at the beginning of the new era. Just now the portable suction-gas plant is coming into practical use in Germany, enabling the farmer, instead of buying expensive gasolene or converting potatoes or other valuable matter by a costly process into fuel alcohol, to take the straw or hay or sawmill refuse, or other vegetable matter growing on the farm, and feed it directly to the producer to be there gasified, generating the required power at no additional heat cost. In order to get the same work output with straw, about four times the weight of coal and forty times its volume must be burnt.

In a 70-h.p. plant a horse-power-hour was obtained with only 2.31 lb. of straw and a little less of hay. Allowing in this particular case, per horse-power-hour, the sum of 1 cent for operating expenses and interest, and a value of $4.40 per ton for straw, it was found that a horse-power-hour cost 1.26 cents with wheat straw and 1.14 cents with oat straw. With the best portable steam engines coal gives the horse-power-hour for 4 cents, and petrol gives about the same, while electric motors run from a distant hydraulic plant cost in the neighborhood of from 12 cents to 16 cents per horse-power-hour. Where the straw has no immediate value and is burn, as is the case on some American farms in the West, the application of this form of gas-power generation is, of course, even more profitable.

In sugar plantations, enormous savings can be effected by burning the bagasse in gas producers instead of under boilers. In some cases, where additional steam coal has to be transported now from considerable distances, this item of expense may be eliminated entirely by the application of gas power, since it gives from three to four times the amount of energy from the available fuel.

It is difficult to obtain data on the above in this country,

since the number of suction-gas plants in actual operation is too small to allow us to arrive at just conclusions as to their relative cost and fitness for competition with other forms of power generation. Conditions differ from those which obtain in Europe, in that there is even a greater variety of prices for the different grades of coal in different localities.

Further, we have in some districts, where natural gas of 1000 B.t.u. is available, a fuel which makes every other form of power production from coal practically non-competitive, so far as present operations are concerned. But natural gas is a declining factor on which no definite claims for future activities can be based. Nor is it available everywhere, while the present enormous output of 393,000,000 net tons of coal can be maintained for an infinitely longer time.

A comparison of the respective cost of power from city gas on the one hand and from suction gas on the other, is even more strictly dependent on local coal prices. It is also, as everywhere else, greatly influenced by the class of service, size of engine, load factor, etc. Competition is more difficult for the gas companies, the larger the capacity and the higher the continuous load on the plants.

It has been estimated that if we allow $2500 as the total cost of a 100-h.p. producer erected; 3 hours' labor per day required by the producer; the engine operating 10 hours a day, 300 days per year; interest, depreciation, and taxes 15 per cent.; engine requiring 12,000 B.t.u. on full load; then in a town where 13,000 B.t.u. anthracite coal may be bought for $6 per ton, the 600 B.t.u. gas must be sold at 27½ cents per 1000 cu. ft. to meet the competition of a 100-h.p. producer plant when the engine carries full load 10 hours per day and 300 days per year.

It is impossible to enter here upon any sweeping statement as to what will be the probable issue of the struggle between the large gas undertakings and the consumers of power gas. Their interests are identical in that both expect to get some concession from the capital invested. This much is certain, that the gas companies will have to yield to the request of continuous users for a rebate by supplying at the lowest commercial profit, otherwise the user will transfer his custom to the independent plant and the gas companies will forfeit the business. The only question still allowing of discussion is whether, even at the lowest

commercial price, illuminating gas will ever rival suction gas for producing motive power, except for very intermittent loads, because suction gas, besides being so much cheaper, is, if anything, better for the purpose than city gas.

Attention is called to an interesting project prepared by B. H. Thwaite, and submitted to the Parliamentary Committee on the London County Council Electric Supply Bill. The proposal was to use a current of 60,000 volts and to bring it into London over a distance of 120 miles from the coal fields. To generate the electricity it was proposed to use gas engines driven by producer gas. It was proposed to use cheap slack and the cost per ton would be only two-fifths of the cost of the fuel used by London electric generators, taking average prices. The sale of by-products would realize 2s. 6d. per ton. The land on which the generating station would be erected would be cheaper, and the saving in rates on about 100,000 kw. capacity would be about 45,000 a year, or about 9s. a year per kilowatt, or 0.033d. per unit sold.

Another plan proposed by Arthur J. Martin provides for the distribution of gas under pressure as the means of conveying power from the coal fields in South Yorkshire to London. The scheme involves a transmission pipe line of over 173 miles, the gas being compressed to 500 lb. per square inch. At this pressure, 40,000 millions of cubic feet, which is the yearly consumption of gas in greater London, could be conveyed by a single line of pipes 25 in. in diameter. The horse-power required to compress the gas would be as much as 40,000 and the cost of the pipe laying, including all incidental expenses, would be roughly, £1,500,000. The annual cost of compression and transmission, including interest and depreciation, works out at $1\frac{1}{3}$d. per 1000 ft., and it is estimated from these and other figures that gas could be delivered in bulk to the existing companies at $7\frac{1}{2}$d. per 1000 cu. ft., and would thus enable them to retail it at a figure which they cannot now approach.

As it is likely that the development of power production and distribution in the more densely populated districts of this country will sooner or later take a course similar to that which it has taken in corresponding sections of Germany, we may expect to see an exchange of energy among the various manufacturing institutions in iron- and coal-producing fields. Those places where coal is

cheap, or waste gases, etc., are available, but which have no market for disposing of the power, will transmit their surplus energy to industrial centers, whence it will be distributed for further use.

The Rhenish-Westphalian Central Station buys power from various collieries and other cheap producers, who are glad to get rid of their surplus energy at a constant profit, and sells it to a number of consumers at a profit. A combination of this kind is especially advantageous for the small power producer and contributor, since, besides running his engines all the time at the highest possible load factor, he need not install spare units. In case of a breakdown he is entitled by agreement to take, for his individual purposes, energy from the line.

Perhaps, if this policy of reciprocal exchange could be extended further, it might help solve the question of competition between the large central stations and gas companies on the one hand and the small independent power producer on the other. If the growing business of the large power companies, instead of being met by an enlargement of their existing plants (which is often very difficult and expensive, especially in large cities where real estate is high), could be amplified by the delivery of additional energy from smaller independent producers, then both parties could sell power at a profit. The small producer, whose plant may be located near the central station and who can generate gas power with as high thermal efficiency as the largest plant, would find a constant market for his surplus power, while the central station with its established business can sell this power at a higher rate, without having to install additional units and reserves, which soon depreciate without bringing adequate returns. Mr. R. E. Hellmund in commenting on this problem suggests that it might be advisable to have induction motors driven above synchronism used as alternators in the plants of the smaller producers, while the main plant should be equipped with synchronous alternators. This would have the advantage that the smaller producers would not need to have as high-grade men as would otherwise be necessary. Such a system would only be possible if the load of the system were always larger than the amount of energy delivered by the smaller consumers into the line. Of course the larger the number of independent contributors and the smaller the amount of their specific contributions, the more difficult will be the satisfac-

tory organization of a combination of this kind, the difficulties being less of a technical than of an administrative nature.

Gas Power for Ship Propulsion

Reference has already been made to the application of gas power for the propulsion of vessels. Ships equipped with suction producers and engines have actually effected a reduction of coal consumption to one-third of that of steam ships. This fact, together with the reduction in space occupied by engines and coal bunkers, and the corresponding gain in cargo space, and the elimination of smoke and smell, makes the adoption of gas power of the greatest importance for vessels which are to possess the maximum radius of action combined with the minimum cost of operation. Therefore, builders and owners of canal barges, tug boats, yachts, etc., ought to devote their most careful attention to this new development.

While there is little or no gain to be expected in bulk and weight of the engine power, the gas producer occupies only about one-third of the space of a water-tube boiler, or one-eighth of that of a Scotch marine boiler, the dimensions depending on the grade of coal burned. In a 7000-ton cargo steamer fitted with gas power, the saving in cargo space effected was 13,000 cu. ft. The weight of a gas producer compared to that of a water-filled boiler of the type such as is installed in yachts and tug boats is from one-fourth to one-fifth that of the latter. The amount of water needed for evaporation is about $\frac{1}{2}$ lb. per horse-power for a coal consumption of $\frac{3}{4}$ pound.

On a trial run a 70-h.p. gas tug consumed in 10 hours 530 lb. of German anthracite against 1820 lb. of steam coal used by the competing 75-h.p. steam tug. This economy so far effected is in the ratio 1 to 3.44 and is certainly encouraging enough to induce capitalists and engineers in this country to investigate this matter before foreign practice gets too far ahead. For the propulsion of larger vessels, the double-acting vertical two-cycle engine is the most promising type to be adopted, since it gives steady and quiet motion with variable speed, quick starting under load, and almost instant reverse when compressed air is employed, such features being the indispensable requisites for successful operation on board ship.

The Deutz Motor Works of Cologne, Germany, who were the first to investigate the technical and commercial possibilities of gas ships, have fitted their suction-gas system on eleven vessels, the power of the various engines ranging from 35 to 90 h.p. Recently they built two flat-bottom barges of 240 tons for river traffic, equipped with engines of 100 h.p., of which one is doing active service between Cologne, Antwerp, and Rotterdam.

The total distance traveled is 187½ miles and the time occupied on the round trip, including all stops, with an average load of 200 tons, occupies 14 days, giving an average daily run of 27½ miles under all conditions, thereby enabling 26 round journeys per year to be accomplished. The cost of the vessel was approximately $11,250, and the annual expense of operation, maintenance, etc., works out as follows:

Depreciation on hull, 5 per cent. on $5000	$250.00
Depreciation on engines, 10 per cent. on $6250	625.00
Interest on capital, 5 per cent. on $11,250	561.50
Insurance	11.25
Navigation dues, 26 round trips	975.00
Fuel anthracite at $5 ton; burned at the rate of 1.32 lb. per horse-power-hour for 75 hours per round trip, 50 hours up-stream and 25 hours down-stream, 117 tons	585.00
Lubricating oil, etc.	243.75
Wages	1750.00
Total annual outlay	$5002.50

During the year 5200 tons of load were carried representing 1,950,000 ton miles, which was done at a cost of about 25 cents per ton. Had the material been transported from Cologne to Rotterdam by the ordinary steamboats the tariff for transport would have been about 50 per cent. higher, while the lowest rate by the railroad would have been five times as much. Another barge of the same capacity is used for the haulage of goods on the Saarbrücken-Mühlhausen Canal, making a round trip of 170 miles which occupies 30 days, including 9 days' detention and 9 days with light load. Under these disadvantageous conditions the cost of transportation by the suction-gas-propelled craft is 33 per cent. lower than that of horse traction, while the boat during the year makes 11 round trips as compared with 7 complete journeys, which were possible by animal traction before the introduction of the new system.

In England, the firm of Thornycroft & Co. has recently built a gas barge which is equipped with a gas plant designed by Emil Capitain, a German engineer who has been very successful along these lines. The barge in question has just completed a trial run over 600 miles in open water. Assuming that the coal used is costing $6 per ton, and that the barge is carrying a net load of 20 tons and traveling at a rate of 6 miles an hour, the cost per hour for fuel is less than 10 cents, if a consumption of 1.2 lb. per brake horse-power is allowed.

In a recent address, delivered by Professor Riedler-Charlottenburg to the Verein Deutscher Ingenieure on the evolution of the steam turbine, the situation was characterized by the following remarkable words: "A development of unprecedented rapidity of one of the most difficult motors in the history of mechanical engineering: a sweeping victory in the power station field: a momentous advance of the highest importance, principally to electrical engineering." If we consider that what was thus described is a new machine which transforms the energy of steam into useful power at a higher degree of mechanical excellence, with a saving in weight and bulk and cost of the prime mover and generator, and with a greater uniformity of turning effort, but with the same low economic efficiency, we are at a loss to give expression to the extreme importance which the evolution of gas power possesses as a factor in the field of industrial economics. It may suffice to draw attention to the fact that this is not the substitution, by a rotary type or prime mover, of a reciprocating engine of the same thermal characteristics, but the complete abandonment of a traditional and wasteful process of power generation in favor of a direct and efficient method. It has not only extended the capacity of our fuel resources to double and more of their former value, but has also enabled us to utilize profitably material and property which was deemed utterly worthless even a few years ago.

We need not point out to those upon whom the technical responsibilities of this particular industry rest how far, by their earnest endeavor, they can help toward the realization of such ideals as are before us. Nor need we dwell on the effect or importance of the scientific study, in our great scholastic centers, of fuel characteristics and conversion as a means for producing proper utilization. It must be patent to all that the more broad-

cast the dissemination of scientific knowledge of everything that is apt to clarify and amplify our understanding of these commodities, the greater must be the industrial progress.

Comparative Mathematical Analysis of Modern Working Cycles

Referring to Fig. 3, *abcda* represents the ideal diagram of the Otto cycle, at full load. An initial pressure $p_a = 1$ atmosphere, a compression pressure $p_b = 12$ atmospheres, a combustion pressure $p_c = 25$ atmospheres, and a temperature $t_a = 300$ deg. C. were assumed. Exponent $n = 1.41$, stroke volume $v_2 = 200$ mm., scale 1 cm. = 1 atmosphere.

On this basis the following data were obtained:

Volume of compression space ..... v_2 = 41.44 mm. (1.63″)
End temperature of compression .. T_b = 618° (1144.4° F.)
End temperature of combustion ... T_c = 1287° (2348.6° F.)
End pressure of expansion .... P_d = 2.08 at. (30.6 lb. per sq. in.)
End temperature of expansion .... T_d = 625° (1157° F.)

Hence the thermal efficiency at full load

$$\eta_t = \frac{Q_1 - Q_2}{Q_1} = \frac{T_c - T_d}{T_c} = \frac{T_b - T_a}{T_C} = 51.4 \text{ per cent.}$$

Assuming quality regulation and the influx of heat at half load reduced to $\frac{Q_1}{2}$, the following values are obtained (diagram *abefa*):

End temperature of combustion ... T_e = 953° (1747.4° F.)
End pressure of combustion .... P_e = 18.5 at. (272 lb. per sq. in.)
End pressure of expansion .... P_f = 1.54 at. (22.64 lb. per sq. in.)
End temperature of expansion .... T_f = 462.5° (864.5° F.)
Thermal efficiency .... η_t = 51.4 per cent.

With quantity regulation the influx of heat at half load is again $\frac{Q_1}{2}$ the active stroke volume $\frac{v_h}{2}$, and $T_g = T_a$, and the following values are obtained (diagram *ghikag*):

End pressure of compression ...... P_h = 5.65 at. (831 lb. per sq. in.)
End temperature of compression .. T_h = 496° (924.8° F.)
End temperature of combustion ... T_i = 1068° (1954.4° F.)
End pressure of combustion .... P_i = 12.16 at. (178.8 lb. per sq. in.)
End pressure of expansion .... P_k = 1.012 at. (14.88 lb. per sq. in.
End temperature of expansion .... T_k = 518° (964.4° F.)
Exhaust temperature .... T'_a = 512° (953.6° F.)
Thermal efficiency .... η_t = 46.8 per cent.

Referring to Fig. 1, *abcda* represents the ideal diagram of a constant-pressure engine at full load. The initial temperature and pressure conditions are assumed to be the same as before. With a stroke volume v_h = 200 mm. the following data are obtained:

Volume of compression space	v_2	= 22.72 mm. (0.895″)
End temperature of compression ..	T_b	= 765° (1409° F.)
Volume at end of combustion	v_3	= 38.22 mm. (1.505″)
End pressure of expansion	P_d	= 2.08 at. (30.57 lb. per sq. in.)
End temperature of expansion	T_d	= 625° (1157° F.)
Thermal efficiency at full load	η_t	= 55.6 per cent.

At half load the influx of heat is $\frac{Q_1}{2}$, and the following data are obtained (diagram *abefa*):

End temperature of combustion ...	T_e	= 1026° (1878° F.)
Volume at end of combustion......	v_4	= 30.46 mm. (1.19″)
End pressure of expansion	P_f	= 1.51 at. (22.19 lb. per sq. in.)
End temperature of expansion	T_f	= 454° (849.2° F.)
Thermal efficiency at half load	η_t	= 58 per cent.

At no load the total efficiency of the process approaches the thermal efficiency of the elementary process which is expressed by the equation $\eta_t = \frac{T_b - T_a}{T_b}$ $\eta_t = 60.8$ per cent.

Referring back to Fig. 3, diagram *ablmoa* represents the condition of sluggish combustion. Assuming a combustion pressure of p_1 = 14 atmospheres, with continuous combustion at that pressure and the adiabatic compression curve *ab* and the end temperature of compression to be identical, the following data are obtained:

Temperature at point *l*	T_l	= 721° (1329.8° F.)
Temperature at point *m*	T_m	= 1124° (2055.2″)
Volume at point *m*	v_3	= 64.6 mm. (2.54″)
End temperature of expansion	T_o	= 655° (1211° F.)
Thermal efficiency	η_t	= 47 per cent.

Under these conditions, which correspond to those of actual practice, the efficiency drops 8.5 per cent. below the ideal, while the efficiency of the constant-pressure diagram is 18 per cent. higher.

In Fig. 3 curve *aqrs* represents the condition of premature

ignition. Assuming that ignition sets in at a pressure $p_q = 2.13$ atmospheres, the following data are obtained:

Temperature at point q . . . . T_q	$= 373.5°$ (704.3° F.)
Temperature at point r . . . . T_r	$= 1043°$ (1909.4° F.)
Pressure at point r . . . . P_r	$= 5.93$ at. (87.17 lb. per sq. in.)
Maximum pressure at point s . . . . . P_s	$= 33.5$ at. (492.5 lb. per sq. in.)

The possibility of such excessive pressures occurring in the working cylinder is a drawback of the Otto cycle which is not inherent in the constant-pressure process.

An investigation of the relations between the mean effective pressures and the maximum pressures, and between the mean effective pressures of the respective cycles, which is necessary for determining the bore and stroke of the cylinder and the dimensions of the working parts, brings out the following points: With equal maximum pressures and temperatures the mean effective pressure of the constant-pressure cycle is 13 per cent. higher than that of the Otto cycle. With the latter, an increase of the mean pressure can only be effected by increasing the maximum pressure of combustion; with the former, by prolonging the period of heat influx. Diagram *abtua* represents such an increase with the Otto cycle, corresponding to a mean pressure of 5 atmospheres. The maximum pressure is found to be $p_t = 31.5$ atmospheres (463.05 lb. per square inch).

The maximum temperature is . . . . . T_t	$= 1620°$ (2948° F.)
The thermal efficiency . . . . η_t	$= 51.3$ per cent.

Diagram *abgha* represents an increased constant-pressure diagram, corresponding to a mean pressure of 5 atmospheres (735 lb. per square inch).

The maximum pressure . . . . P_c	$= 25$ at. (368 lb. per sq. in.)
The maximum temperature . . . . T_g	$= 1500°$ (2732° F.)
The thermal efficiency . . . . η_t	$= 54$ per cent.

A comparison between the two established the following result: For the commercial range equal mean effective pressures are attained in the constant-pressure cycle at lower maximum temperatures and pressures and with a higher degree of thermal efficiency than in the Otto cycle.

Regarding the relation of the negative work consumed to the positive work rendered, diagram *awba* represents the former and

area *awtua* the latter item in the Otto cycle. It is found that the negative work is 29.2 per cent. of the positive work.

In the constant-pressure cycle area *akba* represents the negative and area *akbgha* the positive work, the ratio being 38.4 per cent. It is seen that the negative work expended is smaller in the Otto than it is in the constant-pressure cycle.

Regarding the influence of prolonged expansion on the economic efficiency of the process, it is found to be unfavorable. By prolonging *gh* down to the atmosphere a diagrammatic area *abghia* is obtained, representing a mean pressure of 2.76 atmospheres against 5 atmospheres of the smaller diagram *abgha*. This means that by prolonging expansion the mean effective pressure is reduced to nearly one-half of its value. Hence, to obtain the same capacity with equal stroke, the piston area and, therefore, the maximum piston pressure must be nearly doubled. The increasing thermal efficiency (from 54 per cent. to 60.8 per cent.) is, therefore, more than counterbalanced by the decreasing mechanical efficiency and by the losses through cooling.

Referring to Fig. 2, diagram *abcdea* represents the full-load and *ab′c′d′e′a* the half-load ideal diagram of a Weidmann continuous-combustion engine, while *ghi* and *g′h′i* are the corresponding pump diagrams. The relation of negative pump work expended to positive work rendered is 6.5 per cent. at full load and 8.5 per cent. at half load. The thermal efficiency of the process is 49 per cent. and 50.2 per cent., respectively.

Prof. H. Diederichs, of Cornell University, contributes the following interesting elaboration to the above questions:

"It can be shown that the efficiency of the ideal Otto cycle is in general

$$E = 1 - \frac{1}{r^{n-1}}$$

and that of the constant-pressure cycle is

$$E_1 = 1 - \frac{1}{r_1^{\,n-2}} \qquad \frac{(a^n - 1)}{n(d - 1)}$$

"In these equations, r or r_1 = compression ratio

$$= \frac{\text{stroke volume + clearance volume}}{\text{clearance volume}}$$

n = exponent in the equation pv^n = const. for the compression line

and d = cut-off ratio in the constant-pressure cycle

$$= \frac{\text{volume at cut-off}}{\text{clearance volume}}$$

"Now it is evident from an inspection of the two equations that for the same values of r and n, that is, for the same compression pressure, E will always be greater than E_1. But in practice the operating limit is not due to the compression pressure but to the maximum pressure occurring in the cycle. It then becomes interesting to see what the conditions are when maximum pressures are assumed equal in the two cycles.

"To obtain a basis of comparison the following assumptions were made:

a The maximum pressure in each cycle is 25 atmospheres (352 lb. per square inch).

b Value of $n = 1.37$, an average figure.

c Each cycle is assumed to receive the same quantity of heat, that is, that necessary for the nominal horse-power under the conditions chosen.

d The temperature at the beginning of compression is assumed at 600 deg. F. absolute.

"The diagram, Fig. 11, shows the result of these computations. Efficiencies are plotted from bottom to top. From right to left are given values of d, and from front to back values of r or r^1. In this case r stands for the ratio of compression in the constant-pressure cycle, while r^1 represents the equivalent ratio of compression required in the constant-volume cycle. As an example, if $r = 10$ for the constant-volume cycle, the Otto cycle for the same maximum pressure, that is, 25 atmospheres, and the same amount of heat furnished, would have a ratio of compression $r_1 = 4.9$.

"In the figure, the surface $A\ B\ C\ D$ represents all the possible efficiencies of the constant-pressure cycle for the ranges of r and d covered. In the same way, the surface $A_1\ B_1\ C_1\ D_1$ shows the efficiencies for all the possible constant-volume cycles. The factor d does not appear in the equation for this cycle, hence the efficiencies are constant in this direction. The two surfaces intersect in the line $E\ F$, and for the conditions assumed, therefore, the constant-pressure cycle is superior to the constant-volume cycle for all cycles in the surface $F\ E\ D\ C\ B\ F$. In the only commercial

constant-pressure engine, the Diesel, the value of d at full load is about 2.5, and r is in the neighborhood of 13. It is seen from the diagram that the superiority of the constant-pressure engine is considerable under these conditions. In making comparisons by this diagram it should, however, not be forgotten that the cycles treated are ideal, and that in practice, while the results are similar, the gain due to the constant-pressure principle is probably not so great as indicated.

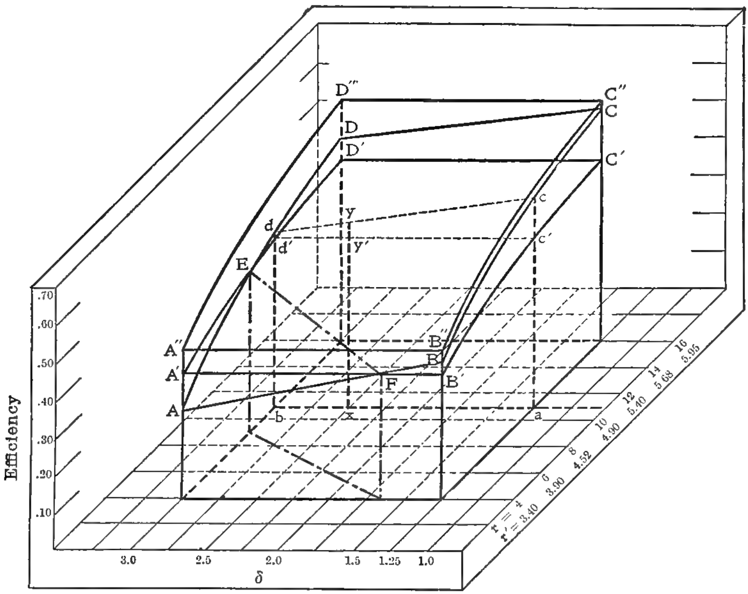


FIG. 11. — Diagram Showing Comparative Efficiencies of Otto and Diesel Cycle.

"The diagram is drawn by isometric projection, and to show how comparison may be made by means of the diagram, assume that the constant-pressure engine has a compression ratio of $r = 11$. The equivalent ratio for the constant-volume cycle of the same maximum pressure (25 atmospheres) and the same amount of heat received would be about $r_1 = 5.15$. Assuming full-load conditions, that is, $d = 2.5$, we proceed as follows:

"From $r = 11$, draw the line a-b parallel to the d axis. From a and b draw lines parallel to the efficiency axis cutting the curve BC in c and the curve AD in d; join c and d. Then from the point

of intersection of $d = 2.5$ and the line a-b draw the line x-y parallel to the efficiency axis. The distance x-y as scaled off on the efficiency axis represents the efficiency of the ideal constant-pressure cycle for the conditions assumed. Next, join the points d^1 and c^1 which represent the intersection of the lines a-c and b-d with the limiting curves of the constant-volume surface. Then x-y represents the corresponding efficiency of the constant-volume cycle. As scaled off, x-$y = 50$ per cent. and x-$y^1 = 46$ per cent. Actual computations show the figures to be 49.8 per cent. and 45.6 per cent. respectively.

"The diagram further brings out the fact that, in theory, the efficiency of the constant-pressure cycle increases with a decrease in d, that is, with a decrease in the load. This is borne out in practice in Diesel engines, where many tests have shown a greater thermal efficiency at three-quarters than at full load. Further down in the load curve this action is overbalanced by other losses in the machine and it no longer appears.

"Finally the surface A'' B'' C'' D'' represents the efficiencies of the constant-volume engine when the compression pressure is the same as in the constant-pressure cycle; that is, r is the same for both. As pointed out, this results in superior efficiencies for the Otto cycle throughout, but in the ordinary operation of the Otto cycle the pre-ignition would prevent the uses of values of r exceeding eight even for the lean gases."

Prof. A. J. Wood, of Pennsylvania State College, enlarges on the same problems as follows:

"It may be noted that the efficiency for the ideal Otto cycle at full load is 51.4 per cent. and for the constant-pressure cycle 55.6 per cent. One might, at first, be led to infer from this that, in general, the Diesel engine cycle gives a greater efficiency than the Otto. It should be noted, however, that the compression volume was different in the two cycles; the author has taken the same maximum pressures in the cases cited. Had the Otto compressed to the same *volume* as the Diesel, the efficiency in the former cycle would have been:

$$\eta_t = 1 - \left(\frac{v_2}{v_1}\right)^{n-1} = 1 - \left(\frac{22.72}{222.72}\right)^{0.41} = 59.2 \text{ per cent.},$$

thus giving 3.6 per cent. in favor of the Otto instead of 4.2 per cent. in favor of the Diesel.

"The efficiency of the Diesel cycle may be expressed in the following form, which will serve to show at a glance its difference from the Otto efficiency:

$$\eta_t = \frac{Q_1 - Q_2}{Q_1} = 1 - \left(\frac{v_2}{v_1}\right)^{n-1} \frac{1}{n}\left(\frac{R^n - 1}{R - 1}\right); \text{ where } R = \frac{v_3}{v_2};$$

from which it is evident that the efficiency will increase as R (or the load) decreases. For example, suppose the load drops off one-half, the influx of heat being $\frac{Q_1}{2}$, then R will decrease 50 per cent., but the efficiency will increase. This is exactly what the author finds.

"Again, turning to the Otto; with quantity regulation, the author shows that the efficiency decreases with decrease of load; examine the equation:

$$\eta_t = 1 - \left(\frac{v_2}{v_1}\right)^{n-1}, \text{ with quantity regulation,}$$

as v_1 decreases (the compression volume v_2 remaining the same) the efficiency decreases; but with *quality* regulation, v_2 and v_1 remain the same and the efficiency of the whole cycle is unchanged — a striking contrast to what is found in the Diesel.

"Do not these observations point favorably to the Otto theoretical cycle in preference to the Diesel on the basis of a comparison for full load and *quality* regulation? One would not hold, of course, that the Otto engine can *practically* compress to the amount of the Diesel and then explode the charge at constant volume. I am referring here to the theoretical cycles only."

PART II

DESIGN AND CONSTRUCTION OF LARGE GAS ENGINES

III

GENERAL CONSIDERATIONS

In presenting a treatise on this subject to American engineers, it is not intended to enrich the technical literature of this country by a treatise of the speculative kind — prophesying the probable course of future development — nor is it the aim of the writer to dwell at length on the historical evolution of this modern branch of engineering, nor to consider questions of purely theoretical thermal interest and design.

Too much has been said in technical papers on the qualitative or inventive part of the question, and, with few exceptions, all handbooks published on the subject treat their matter almost exclusively from a descriptive standpoint, repeating the views of authorities and copying tests and descriptions found in catalogues of manufacturers, without even attempting to express individual ideas or trying to criticize the actual conditions concerned. A step in the right direction has recently been made by Hugo Güldner, an eminent engineer of Munich, Germany, whose remarkable book on the "Design and Construction of Internal Combustion Engines" must be pronounced as the first successful attempt to write a scientific and, at the same time, practical handbook for the exclusive use of those engaged in building this kind of machinery, or who are already familiar with its characteristics.

Another book on gas-engine design has recently been published in this country, which treats exclusively of the quantitative side of design, and deals with the forces in and the energy-transforming power of the standard mechanism of the exploding gas engine. This work by Dr. Lucke, Professor at Columbia University, represents the first comprehensive and scientific treatise on this subject in American technical literature.

It is only when we approach the gas-engine question in a similar way as indicated by the above-named publications, namely,

equipped with a complete knowledge of ordinary machine and steam-engine design, that we can rationally help its progress. Neither can an inventive speculation, nor the fantastic interpretation of incidental results, nor theoretical thermal considerations of diagrams, taken under conditions of practical excellence, serve to solve the problems involved in rational gas-engine design or benefit those interested in the commercial side of the question.

The following chapters are based on practical grounds — experience and facts gained on the continent. Questions of qualitative design will be omitted altogether, and such types of engines only be dealt with as have actually been built and for several years have shown results such as to justify their presentation as a standard mechanism.

It is hoped that such presentation may help to direct the attention of American engineers more toward the subject of large gas engines, which has hitherto been undeservedly neglected in this country, and that it may benefit all those whose interests demand an intimate knowledge of this modern branch of engineering. It may be added that the following treatise presupposes the familiarity of the reader with the fundamental physical and chemical laws, and with the elementary principles of steam and gas-engine design and construction.

Economic Attainments

Before discussing the merits and demerits of the various makes and systems, it may be well to summarize briefly those data on the economy of gas engines which have been established beyond discussion by the experience of recent years.

A general comparison between the thermal and economical efficiencies of steam and gas engines, for purposes of pronouncing the superiority of one prime mover over the other, being useless though often drawn, it is sufficient to remember that, in modern steam-engine practice, of 100 units of heat introduced as fuel into the boiler, 24 per cent. is lost through radiation and gas flux to the chimney, 12.7 to 15.7 per cent. (the latter with superheating) is utilized as effective work, while the rest is lost in the condenser. A waste-heat engine of the binary vapor type being attached to the plant, it is possible to recover 6.75 per cent. of the condenser loss as useful work.

In the gas engine we have through the generation of gas in the producer a loss of 16.5 per cent.; through cooling water an additional loss of 21.5 per cent.; through exhaust gases another 20.5 per cent., while from 19 to 23.2 per cent. is gained as useful or available work.

Figure 12 gives a simple graphic representation of how progressive engineering has gradually and steadily increased the thermal efficiency of engines from the original hot-air type up to the internal-combustion engine, which holds now its undisputed rank as by far the most economical of all.

Figure 13 shows diagrammatically the relative thermal efficiency of modern steam and gas engines and the losses occurring through the conversion of combustible matter into work, in the respective processes.

In the diagrams, Figs. 14 and 15, the curves for heat consumption per brake horse-power, as well as for the mechanical efficiency, of six modern German internal-combustion engines have been plotted, together with the limitation curves for an ideal steam, and an ideal blast-furnace gas engine, working without heat loss. It will be seen that with the exception of types I and II representing single-cylinder machines, gas engines have now, at higher loads, actually attained a thermal efficiency rivaling that of the hitherto most economical prime mover, the Diesel oil engine, III, consuming less than 2000 cal. (7900 B.t.u.), per horse-power-hour, thus leaving even the ideal steam engine far behind.

The purely thermal superiority of the gas engine does not, however, allow of any premature conclusion as to the final answer that can be given to the question, still allowing of serious discussion nowadays, namely, "Gas Engine or Steam Turbine?" For in the complete commercial-economy coefficient, thermal efficiency is but a small factor when compared to initial capital outlay, heat cost, maintenance, floor space, and other factors, all of which, in the problem of securing maximum industrial economy for a heat-power plant, are deserving of our most careful consideration.

There are, however, conditions when the factor of heat cost does not enter at all; at least seemingly not; for instance, in iron-smelting plants, coal mines, and wherever gas is generated as a by-product, and, of course, in the natural-gas region. Here it no longer is questionable as to what prime mover is to be

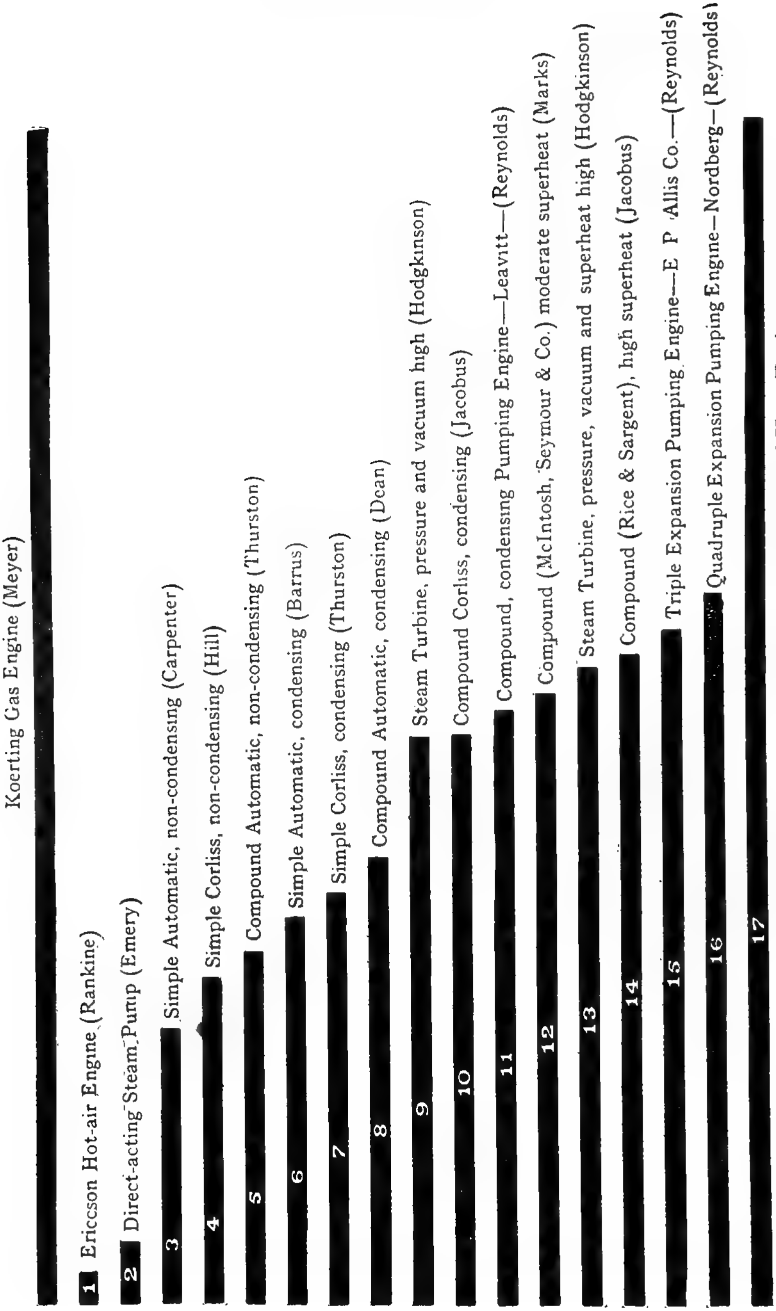


FIG. 12. — Diagram Showing Increasing Efficiencies of Heat Engines.

chosen, but which of the two is better adapted to the service required, such service being mainly the driving of blowing engines, rolling mills, and dynamos for central stations.

In Fig. 16 the characteristics of all gases which can be used for the production of power in gas engines, together with the by-products gained in their generation, are shown. It need not be mentioned that illuminating gas can no longer be regarded as a commercial fuel for use in large gas engines, such as are to be discussed in these chapters.

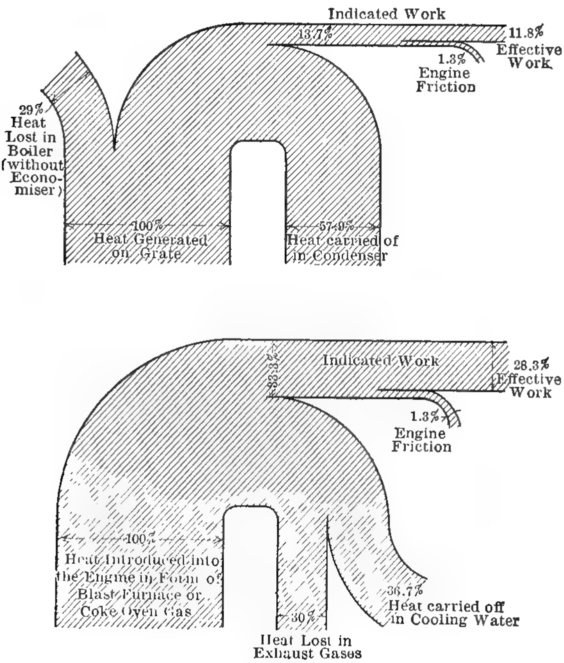
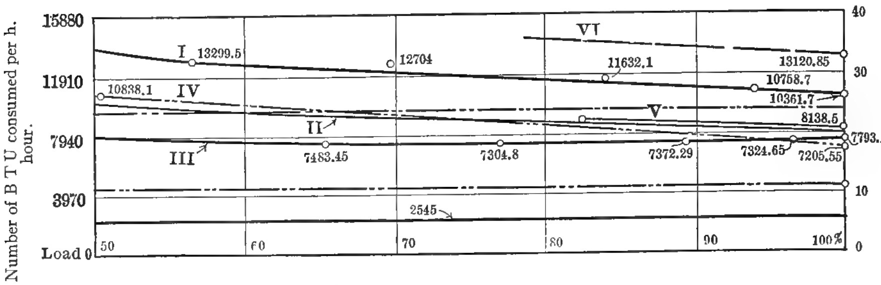


FIG. 13. — Diagram Showing Relative Losses in Steam and Gas Engines (Riedler).

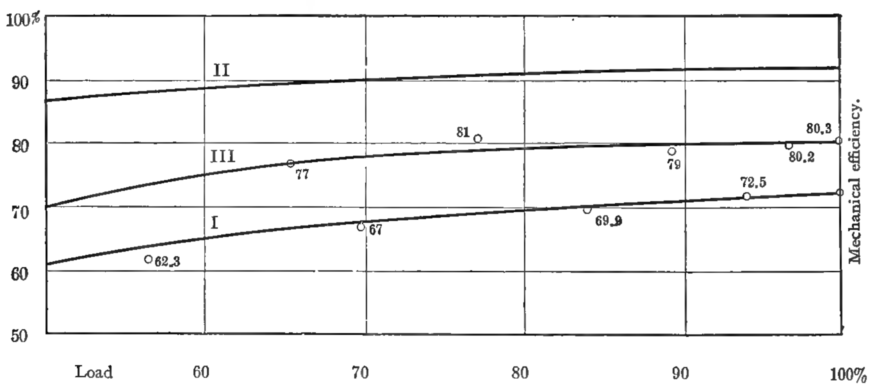
In a country like Germany — so poor of natural resources when compared with America — the problem of economic power production has become a serious factor long ago, and has forced the engineer to direct his energies toward the perfection of generators and motors which would utilize the lowest grade of fuel and waste products. It is natural, therefore, that the oil, coke-

oven, and blast-furnace gas engines were first brought to a state of perfection in that country.

We may guess, in this country, at the enormous gain that can be made by a more economical utilization of waste gases by studying the surprising results attained abroad.



I — 750 B. H.-P. Single-Cylinder Blast-Furnace Gas Engine.
II — 750 B. H.-P. Tandem Blast-Furnace Gas Engine.
III – 70-90 B. H.-P. Single-Cylinder Diesel Engine (Oil).
IV 30 B. H.-P. Single-Cylinder Water Gas Engine.
V – 50 B. H.-P. Single-Cylinder Illuminating Gas Engine.
VI – 50 B. H.-P. Single-Cylinder Gas Engine.
— - - — - - — Ideal Steam Engine.
— · - — - - — Ideal Blast-Furnace Gas Engine.
———————— Heat Equivalent of One Horse-Power.



FIGS. 14, 15. — Curves Showing Heat Consumption and Mechanical Efficiencies of Various Types of Gas Engines (Riedler).

In the production of 1 ton of pig iron there are generated — if we deduct losses in the stove and a certain quantity for heating the blast — in the neighborhood of 2500 cu. m. (88,275 cu. ft.) of blast-furnace gas available for power purposes, such gas having a calorific value of from 750 to 1000 cal. per cubic meter, or 84 to 112 B.t.u. per cubic foot. This volume of gas,

when used in a steam plant, would only give in the neighborhood of 250 horse-power-hours, while, when burned in a modern gas engine, it will generate from two to three times this amount of power.

As the annual production of pig iron in Germany averages 10,000,000 tons, there are now, from the adoption of blast-furnace

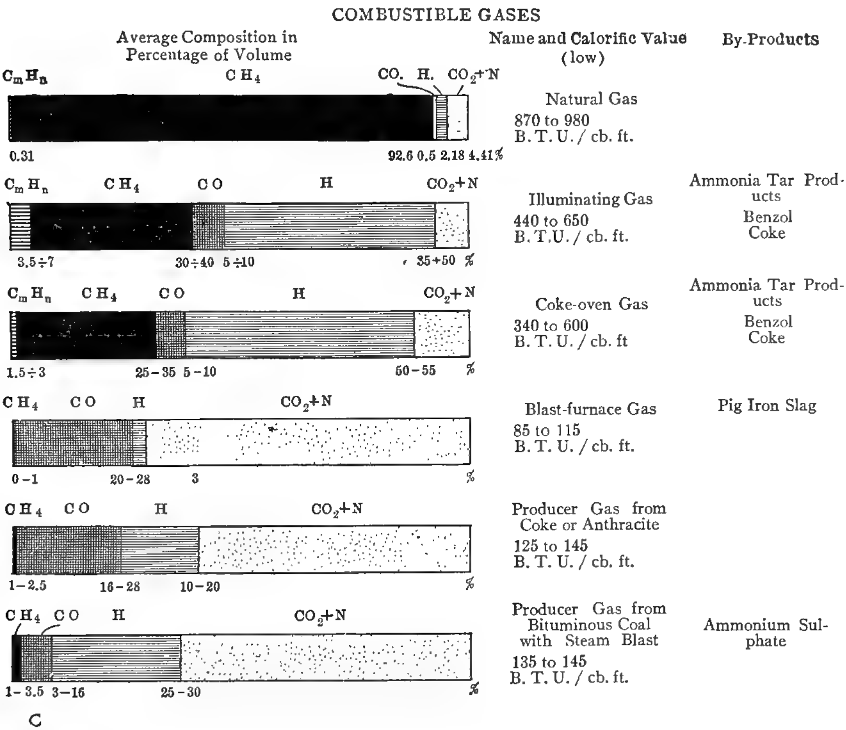


FIG. 16. — Characteristics of Combustible Gases.

gas engines, 1,100,000 h.p. available as useful work, which was formerly wasted. There are similar conditions prevailing in the coal regions. One ton of coal in coking generates 250 cu. m. (8827.5 cu. ft.) of purified gas, having a calorific value of about 3500 cal. per cubic meter, or 393.51 B.t.u. per cubic foot. Of these, 150 cu. m. (5296.5 cu. ft.) are used for heating the ovens, so that there remain 100 cu. m. (3531 cu. ft.) of gas, which, when burned in a gas engine, will produce from 110 to 160 h.p. For

every ton of coal burned to coke in 24 hours, there are then 5.5 h.p. available for other purposes. In 1903 Germany's output averaged 11,000,000 tons of coke, 15,000,000 tons of coal being used for such production, which is an efficiency of transformation of 73 per cent. By the perfection of engines for the utilization of coke-oven gases there are generated, then, 225,000 h.p. a year, which were formerly wasted.

For central-station work the gas engine has, to a great extent, already displaced the reciprocating steam engine. Up to 250-h.p. sizes, anthracite and coke plants equipped with suction-gas producers were hitherto the most convenient and economical to install, while now lignite, brown coal, and peat briquets are preferred. Beyond this, bituminous coal or dust coal is the most desirable fuel to use, at least in Europe, since in producers of modern type any grade of coal which contains up to 50 per cent. of ashes, and which does not cake excessively, will suit.

The economy of producer plants, it is known, depends especially on their size and load factor. Fullest economy is obtained when the waste heat of the plant is used for steam raising, also when the fuel contains sufficient nitrogen recoverable as ammonia. It would not pay, however, to install apparatus for the recovery of by-products under sizes of from 3000- to 4000-h.p. plants.

Owing to this recovery, which represents a direct saving in fuel cost, and owing to the fact already referred to, that in producers an inferior grade of coal can be used, which may be supplied at less cost than coal for use in steam boilers — proportionately to its calorific value — it follows that in stations of several thousand horse-power size the gas plant must finally displace the steam plant.

Moreover, when we consider that a central station, if equipped with a gas plant, will involve a capital outlay approximately the same as with a steam plant, and that the actual fuel consumption, if worked at full load continuously, will be reduced somewhere in proportion of 100 to 83, or lower, depending on the grade of coal used, and if worked with a load factor of 25 per cent., in the proportion of 100 to 35, then we are bound to acknowledge the superiority of the gas system and adopt it wherever power plants are to work with highest commercial economy. Of course, there are so many factors bearing on the comparison between gas and steam plant that these figures cannot be generalized.

It may be added that the system of treatment or purification from dust and tarry products, of the various gases, has been, by the construction of centrifugal gas washers, so perfected that buyers of such apparatus are guaranteed a gas containing only 0.05 g. of dust per cubic meter, which is a sufficient degree of cleanness for use in engines. Construction and working of these washers, which in reliability of operation, efficiency of cleaning, and reduction of floor space occupied are immeasurably superior to the old-time scrubber plants, and have done a great deal toward the successful utilization of waste-power gases in large engines, have been treated in a later chapter.

Thermal Considerations

Gas and air, perfectly mixed in the proper chemical proportions, are introduced at nearly atmospheric pressure into the working cylinder, where they are compressed up to the limit of self-ignition and ignited at several places so as to facilitate flame propagation and attain maximum rapidity of combustion. Highest possible compression of a perfect mixture and generation of heat at an early part of the stroke are, then, the fundamental laws of all-around efficiency in modern engines. There is nothing new about the internal-combustion process proper; for years past such treatment of the charge has been preached as being the only possible and rational way to practical excellence.

Dugald Clerk's method or theory of increasing the density of the working medium in order to reduce flame decomposition, by introducing an additional charge of air or neutral gases so as to increase the end pressures of compression without raising its end temperatures, has not found favor with continental builders.

The fact that reduction of flame temperatures in Clerk's method can only be had at the expense of reducing the rapidity of heat influx — in other words, adding heat in the latter part of the stroke, thereby increasing the cyclic end temperatures and heat loss through the exhaust — the other fact that high temperatures have never, so far, formed a limiting condition of design, and last but not least, the lowering of mechanical efficiency by the addition of a pump, all this has been the cause why Clerk's experiment has not had that overthrowing effect on the working process of gas engines that his enthusiastic admirers were led to expect.

For the manufacturer of four-cycle engines, the question is deserving of careful consideration, whether by the adoption of separate pumps for the preparation and delivery of part of the charge he will not deprive his machine of that only advantage which he is still justified in claiming over the two-cycle type, namely, that the preparation, combustion, and expulsion of the energy-transforming medium are performed by the piston and in the cylinder of his engine in a simpler way, with a high degree of efficiency and without the use of auxiliary machinery.

We must naturally hesitate to complicate the simple mechanism of an engine if the thermal gain expected is outweighed by a mechanical loss, and, after all, it cannot be denied that there are four-cycle machines on the market like the Güldner motor, which shows a thermal efficiency (indicated) of 42.7 per cent. at full load, without pump, while the best result attained by Clerk's National gas engine, using a cross-guide pump, is 34.4 per cent.

For the designer of gas engines, the Clerk experiments are of interest only in so far as they show, or, rather, emphasize, the necessity of adding heat early in the stroke, and show what can be done only by perfect mixture, high compression in a clean chamber of simpler forms, and provocation of ignition at several points of the mass of gas.

From the table of gases, Fig. 16, it will be seen that blast-furnace gas, because of its high percentage of carbon monoxide and its small hydrogen content, will best comply with the fundamental requirement of high compression. It is this characteristic which has done a great deal toward facilitating the commercial perfection of large gas engines. On the other hand, highest thermal efficiency has always been obtained with the richest gases.

So far as scientific research has been able to analyze the very complicated process of internal combustion in gas engines, Dr. W. Nernst, professor at the University of Göttingen, has lately presented a résumé of the results of investigations made by the following distinguished scientists: Bunsen, Slaby, Meyer, von Wartenberg, Linde, Bodenstein, Langen, Holborn, Austin, Berthelot, Vielle, Mallard and Le Chatelier, Pouget, vant. Hoff, Clerk, and Dixon. It reads as follows:

1. The maximum amount of work which it is possible to gain by the combustion of matter can in some cases be accurately — in most cases approximately — determined.

2. The maximum pressure of explosion produced by the ignition of a combustible gaseous mixture in a closed vessel has been closely examined by practical experiments made by different observers. It may also be theoretically calculated from the heat of combustion, and from the specific heat of the constituents of the burned gases, if the rise in temperature is not excessive. At very high temperatures the pressure effects observed remain considerably below those determined by calculation, probably in consequence of the strong undulatory fluctuations occurring in the mass of burned gases.

3. At the maximum temperature of explosion, and mostly as a result of the great rapidity of reaction, an almost complete chemical equilibrium is established. At these high temperatures chemical compounds are often formed like ozone, O_3, hydrogen superoxide, nitrogen monoxide (stickoxide), which would be unstable at lower temperatures. For a few simple cases this state of chemical equilibrium can be regarded as sufficiently clarified.

4. The propagation of inflammation in a gaseous explosion is accomplished partly by slow conduction of heat from one layer to the adjoining, partly by self-ignition as a result of the development and propagation of pressure of very strong compression waves (Berthelot explosive wave). Both kinds of inflammation allow a fairly accurate examination of their fundamental characteristics.

5. In mixtures capable of rapid combustion the slow flame propagation by conduction of heat, after having traveled a longer or shorter distance through the mass of gas, is finally transformed into an explosive wave. The development of such explosive wave may be accelerated by reflection from compression waves, or by placing obstacles in the path traveled by the slow combustion.

This question, together with the other regarding self-ignition of gaseous mixtures by compression, which is closely connected with the first, requires considerable investigation by careful experiment before it can be definitely settled.

6. The cooling of a highly heated mass of gas at high temperatures is chiefly due to radiation; at lower temperatures to the effect of conduction and conversion.

On the combustion of liquid fuels, Professor Lucke made a

few years ago, interesting experiments in the laboratory of Columbia University, the results of which were presented at the New York meeting (December, 1901) of the American Society of Mechanical Engineers, and can be found in the *Transactions* of that society.

Mr. Dugald Clerk appears to have been impressed with the nebulous condition of available information on the specific heat of gases at high temperatures and pressures. He was consequently led to make an independent investigation into such matters, and the results he obtained were communicated to the Royal Society, England, by the Hon. C. A. Parsons, F.R.S., in a paper, "On the Specific Heat of, Heat Flow from, and other Phenomena of the Working Fluid in the Cylinder of the Internal-Combustion Engine." This paper suggests an entirely new method of determining the specific heat of gases at high temperatures and pressures, which will be interesting not only to those concerned with gas power, but also to physicists and scientific men generally. Mr. Clerk is able to show how it is possible, with reasonable accuracy, to differentiate between the two kinds of heat losses, those due to the external work rendered by the gas charge and those due to conduction from cylinder to jacket, and by an ingenious and entirely rational method of treatment, using the well-understood terms expressing mean specific heat in work units, he obtains expressions for calculating the latter, which enables him to give tables of apparent specific heats at temperatures from 0 deg. C. up to 1500 deg. C. These figures show a striking increase of specific heat at the higher temperatures, amounting to 31 per cent. as between 100 deg. C. and 1500 deg. Centigrade.

Mr. Clerk states that these apparent specific-heat and heat-flow values now make it possible for the first time to study the thermodynamic problems of the internal-combustion motor from the indicator diagram only, and this he believes will materially hasten the development of a complete theory of these motors by making it possible to determine the principal properties of flame in the engine cylinder itself. Many obscure phenomena are capable of investigation by the method. He then arrives at the following conclusions:

"(1) The apparent specific heat of the working fluid of the internal-combustion engine (consisting mainly of a mixture of

nitrogen, carbonic dioxide, steam, and oxygen), when calculated from the first 0.3 of the engine stroke, undoubtedly increases between the observed temperatures, 300 deg. C. and 1500 deg. C., but tends to a limit at the upper temperature.

"(2) The apparent change in specific heat is not entirely due to a real change of specific heat, but requires in addition continuing combustion to account for all the facts.

"(3) The rate of heat flow from the working fluid and its inclosing walls for equal temperature differences varies throughout the stroke. Increased heat flow accompanies increased mean density.

"(4) The mean temperature of the inner surface of the inclosing walls varies with the portion of the stroke examined from 190 deg. C. for whole stroke to 400 deg C. for first 0.3 stroke under working conditions at full load. These mean temperatures, however, are not the highest mean temperatures reached by the walls.

"(5) The heat distribution during the operation of the working fluid can be determined with approximate accuracy from the apparent specific-heat values and heat-flow values obtained from the diagrams only."

Four-cycle versus Two-cycle

This question has, on the continent and everywhere, arrived at a point of heated controversy. The lecture of Professor Riedler, of Charlottenburg, treating on the subject of large gas engines, which was given before the Society of German Engineers, some time ago, and which was strongly in favor of the four-cycle type, has provoked a universal discussion, in which the representatives of the two-cycle movement, Körting, Oechelhäuser, Borsig, Güldner, and others took an active part.

Of course, such questions cannot be settled by theoretical discussion, only clarified. Practice will have to give the final answer. The writer is strongly in favor of the two-cycle machine and believes that the adoption of high-speed fans for scavenging, and the separation and, perhaps, centralization of all pumps similar to the system of central condensation in steam plants and their regulation by the governor of the engine according to the load, will bring about the desired result of decreased pump work, on which the whole question hinges.

It was mentioned before that the necessity has made itself

felt to disburden large four-cycle engines of the suction work, by equipping them with special fans for the delivery of gas and air. Since large producer plants are now invariably fitted with a fan between producer and engine, in order to draw the air through the fuel bed and the washers, the gas is, even now, delivered at a pressure slightly above the atmospheric.

A full discussion of the two-cycle principle will be found in the chapters treating upon the representative systems of that class.

Systems of Governing

Generally speaking, that system of governing will be pronounced the best which will, under working conditions, secure

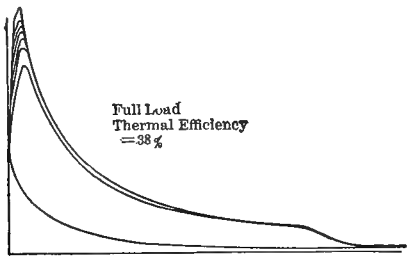


Fig. 17. — Indicator Cards Obtained with Quality Regulation at Various Loads.

regularity of running with the least change in fuel economy when the load is varied from maximum to minimum. This, however, does not always hold true, as, for example, with blast-furnace gas engines, where, at light loads, there is seldom a possibility of utilizing the surplus gas generated and not burned in the engine. It is, therefore, useless for the designer to provide elaborate means for regulating except in cases when economy is a serious factor, as in producer-gas power plants and wherever fuel is costly and can be stored or used otherwise.

There are now three systems of governing employed. In the first, the quantity of the mixture remains constant under all conditions of load, while its quality is changed by varying the gas supply. This method obviously regulates the power of the engine by regulating the calorific value of the mixture and thereby the initial pressure due to combustion. (See Fig. 17.) It possesses

the merit of maintaining constant compression, but the disadvantage of impairing the combustion efficiency of the mixture at light loads.

Uniformity of quality throughout the whole mass of the mixture has been neglected in latest constructions, as the gas valve is regulated so as to open later and later with decreasing load, thereby diminishing the time allowed for diffusion of air and gas, and allowing the richest charge to enter last, so as to fill the space near the igniting device. This method has the disadvantage that, by unavoidable molecular disturbances of the gases passing the inlet, layers are formed, some of richer and some of poorer composition, which, when ignited, produce irregular combustion in consequence of variations in the rapidity of flame propagation and inflammation. As a matter of fact, it is impossible to use this method of regulation for very light and no loads, the inflammability of the diluted mixture becoming sluggish and sometimes arrested altogether — especially when lean gases are used — so that often several successive cylinder charges are exhausted unburned. So it becomes necessary at low and no loads to shut down entirely one of the cylinders of a tandem or twin-tandem engine, and the engine is no longer under the perfect control of the governor. The process is uncontrollable, involves great losses of energy and can be advocated only in cases where gas economy and regularity of running at light loads are secondary considerations.

A better method, and one which is now almost universally used in large engines, when close regulation is required, is to let the richness of the mixture remain unchanged while the quantity admitted to the cylinder is automatically varied by the governor, according to the power required at the moment. This is done either by throttling through the whole length of the stroke, or by cutting off the supply at some point corresponding to the demand. The latter method was first employed by O. Köhler in 1886. It reduces the negative suction work but necessitates a special regulation of the mixing valve, similar to what is done with quality governing. The merit of this system is that it gives uniformity of composition of the mixture at all loads; its chief disadvantage lies in the decrease of compression with decreasing load. It must be stated, however, that even with low compression, ignition of a uniform charge of gas and air

mixed in the proper chemical proportions is provoked much more easily and combustion secured more regularly than in the first system, as can be readily seen from the diagram, Fig. 18. Of

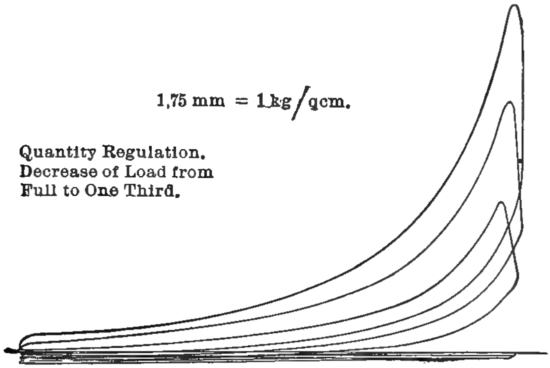


FIG. 18. — Indicator Cards Obtained with Quanity Regulation at Various Loads.

course, the thermal efficiency of such combustion decreases somewhat in proportion to the load. It will be noted from the diagrams that the negative pump work which is indicated by the slope below the atmospheric line, and which covers the work expended for exhausting and suction, incloses in four-cycle engines, working with quantity regulation, a somewhat larger area than what is obtained with quality regulation, where this slope remains identical for all loads. So the advantage of superior combustion is compensated by the larger pump work required. There is this advantage, that the medium negative pressure of compression decreases with the medium positive pressure of expansion, tending to preserve constant the relation between positive and negative crank effort. Moreover, the friction resistances are also reduced with decreasing compression, which has a favorable effect on the wear of the engine, and the high vacuum created during the suction stroke draws the lubricating oil to all parts of the cylinder surface, thus securing better lubrication and increasing mechanical efficiency. Engines using this method of governing show their highest efficiency at full load, and the economy drops off very rapidly when the load decreases. Since in most cases gas engines do not, under normal conditions, work at more than 70 to 80 per cent. of their maximum capacity, it is

obvious that they are less economical in practice than guaranteed by the manufacturers, who always base their figures on maximum load.

Engines using the first system cannot reduce their gas consumption at no load below 60 per cent. of the consumption at full load. With the second system, the no-load consumption may be as low as 25 to 30 per cent. of the full-load consumption.

The characteristic feature of quantity regulation, namely, decrease of compression with decreasing load, introduces, it is said, certain advantages in the kinetic and mechanical relations of the engine but here, also, are difficulties involved in the scheme. With decreasing compression, the end pressure occurring at the dead point drops below that pressure which is necessary to accelerate properly or retard the extra-heavy masses reciprocating in a tandem engine, and there is often anxiety expressed on the part of the designer that knocking may occur at low loads. But the fact is that cushioning does not serve the purpose, as often maintained, to absorb completely the pressure produced by the inertia of the heavy masses of metal. Whatever event is to time the reversal of pressure which must necessarily occur, it must take place before or after the dead-center position of the piston, as hereby knocking is more efficiently prevented. This we can obtain with proper balancing and perfect lubrication just as well at the lower as at the higher compression pressures, for even at the normal compression used in modern practice (12 atmospheres = 170 lb. per square inch), there is danger that the reversal pressure may take place just at the critical point.

Thus the fact of decreasing compression need not limit us in the adoption of quantity governing, even with tandem engines (which represent, of course, the most unfavorable case on account of the heavy reciprocating masses which have to be retarded or accelerated), if we only take care to provide otherwise for good balancing and perfect lubrication.

Another drawback connected with quantity regulation is due to the fact that at low loads a high vacuum is created during the suction stroke, which tends to lift the valves from their seats unless strong closing springs are provided. As will later be seen, there are now constructions on the market which lock the valves during the critical period without introducing much additional complication. Yet it must be conceded that large valve-closing

springs are difficult to place. They also increase the resistance of the valve-actuating mechanism and, altogether, put the quantity system at a disadvantage, against quality regulation, so far as the mechanical execution is concerned, unless some good relay system is adopted.

The first method is superior to the second for loads 10 to 20 per cent. below maximum in that a high degree of compression is

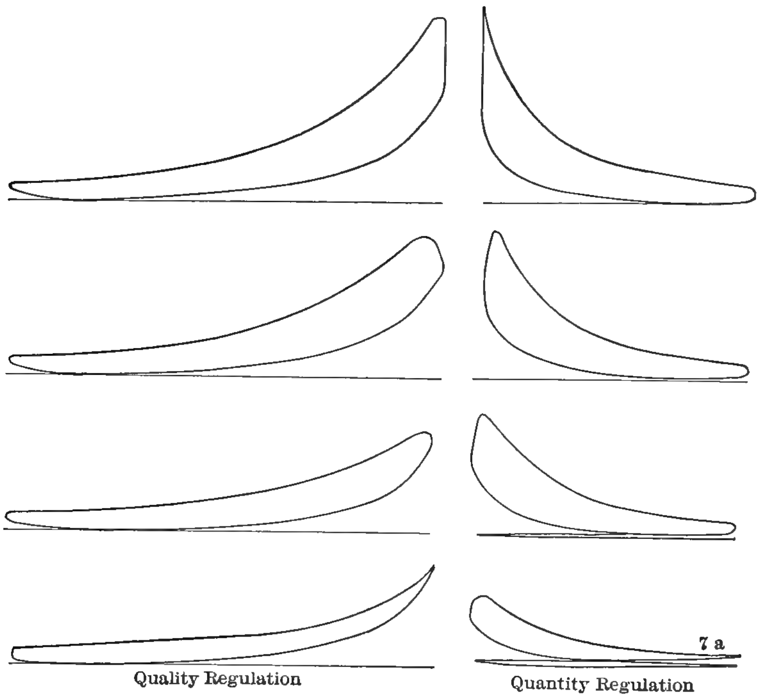


FIG. 18a. — Diagrams Showing Relative Combustion Efficiency of Quantity Regulation and Quality Regulation, at Various Loads.

secured, while the richness of the mixture is still sufficient to produce regular and rapid combustion, so that the economy from normal to full load remains almost constant. (See Fig. 18a.)

Since both quantity and quality regulation have their respective merits and deficiencies, it is obvious that one should try to combine the two by employing high compression of a leaner mixture, a system of supercompression. This method was originated by Letombe, and has been adopted in the engines built by

the Société Anonyme d'Exploitation des brevets Letombe, in Lille, France. At decreasing load the mixture is made leaner by throttling the gas supply, while the quantity of the charge, and therefore its compression, is increased. (See Fig. 19.) It is remarkable that the Letombe engines, using this thermally excellent way of governing, do not show any greater economy than other makes. This fact is a confirmation of the point made in an earlier part of this book, namely, that thermal efficiency is not

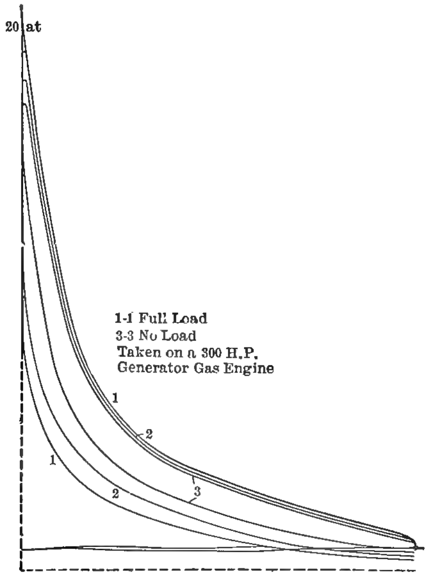


FIG. 19. — Indicator Cards Obtained with Letombe's System of Combination Governing at Various Loads.

the controlling factor in the commercial-economy coefficient. Design of details and workmanship must be quite up to the thermal excellency of its working cycle if superior results are to be obtained in a large gas engine. Another combination method which is coming into universal use in Germany is that of Mees, of Düsseldorf, the fuel curves of which are shown in Fig. 20. His engines work from normal up to maximum load with a qualitative, and from normal down to no load with quantitative regulation. Thus highest economy is attained under normal conditions, the

engine taking in a full charge of gas and air, mixed in proper chemical proportions. With increasing load the quantity of gas admitted is increased, but the efficiency remains, practically, almost constant up to maximum capacity, where it is more or less reduced — according to the degree of overload — similar to steam-engine practice. From normal load down the quantity of the charge is diminished, its quality remaining the same. Compression, therefore, decreases also, but is always kept higher than the corresponding compression of an engine working with pure quantitative regulation, as with the latter throttling begins at a load immediately below the maximum.

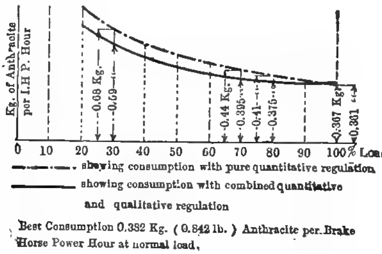


FIG. 20. — Economic Results Obtained with Mees' System of Combination Governing.

While the Mees system is undoubtedly a step in the right direction, it is, in my opinion, difficult to use it where a wide range of overload capacity is required. In practice, when a proper mixture of air and gas is used for normal load, the excessive addition of gas results in knocking and premature ignition. Another difficulty consists in having no device which would give anything like a perfect mixture. We do not possess means for observing a definite, enforced and regulable ratio of gas to air.

Yet for purposes of close regulation and economy one of the combination methods is advisable. This is practised in many engines, though not generally made known; for example, some of the Deutz engines officially use pure quantitative regulation, while in reality provision is made to attain a richer mixture at lower load by throttling the air and increasing the gas supply.

The difference in fuel economy between the combination and the ordinary methods of governing is considerable, as will be seen from the accompanying curves, Fig. 20, attained with a Mees

engine. It need not be said that the firing point is always adjusted by hand to suit the quantity and quality of the mixture.

In the Görlitz and Union engine built by Reichenbach, the governor controls both the quantity and the quality of the mixture, and at the same time adjusts the igniter so that with the least compression the point of ignition is most advanced. In connection herewith may be mentioned the various devices for locking the sparking apparatus, when the conditions of the engine are such that ignition would be harmful. In some makes the sparker is automatically pushed back to a point of late ignition when the engine is started. In others the electric current is automatically switched off when the water circulation in the piston or the jacket becomes defective, or when the temperature of the cooling water exceeds a certain limit. It is not deemed necessary to give in this chapter a detailed description of these automatic safety devices, as they are very simple and their mechanical arrangement may be wholly left to the ingenuity of the designer.

The various systems of governing in two-cycle engines will be fully discussed later. It may be mentioned here that all such engines, using independent and efficient pumps, have the advantage over the four-cycle that perfect expulsion of the burned gases is obtainable by scavenging. Thus the combustion efficiency of the new charge is not impaired by the products of the former combustion, which, in four-cycle engines, form a nearly constant factor, diluting the mixture in a cumulative ratio with decreasing load.

Summarizing the above considerations, we are led to the following ranking of the systems of governing in order of merit: (1) For close regulation and economy (lighting service), combination system; (2) quantity governing; (3) for crude regulation, regardless of economy, as for driving blowing engines and rolling mills and pumps, quality governing. This ranking is based on the present state of our knowledge. Moreover, the following problem presents itself to the designer: Theory and experiments have evidenced that in the system of quality governing, which is characterized by the feature of constant compression with variable load, the economy may be kept constant for all loads if we could only secure regular combustion at low loads and with lean mixtures. We must, therefore, try to find some mix-

ing process which will produce, under constant compression and increasing influx of air, perfect combustion even at no load; in other words, which will, contrary to the hitherto uncontrollable methods, *enforce* combustion under the varying conditions of temperature, pressure, speed, and composition.

As to the effect of the governor on the regulating process or *vice versa*, it is evident that the closeness of regulation of a heat engine will be the greater, the quicker the governor will adapt itself to sudden fluctuations of load, and the smaller the continuous difference of the number of revolutions per minute between full load and no load. The action of the governor will, therefore, be the prompter, the less frictional resistance there is to be overcome in the controlled mechanism and gear, or the less back pressure is acting upon it. This means, on the other hand, that the greater the reactionary forces of the moving parts the more powerful must be the governor to counteract them promptly. In twin-tandem engines there is a considerable back pressure exercised on the governor. Thus it will be seen that dust or tar or other impurities in the valve system must have a retarding effect on regulation, and when accumulating in excessive quantities will make regulation entirely impossible.

Generally speaking, the coefficient of regularity should remain at fluctuations from full to no load between 3 and 4 per cent. Sudden load fluctuations of 25 per cent. should not provoke a momentary variation in the number of revolutions greater than $1\frac{1}{2}$ per cent. Of course, the scope of these requirements depends entirely on the class of service for which the engine is intended.

Some firms like Deutz employ for every one cylinder of a tandem or twin-tandem engine an individual governor, all governors being interconnected by rods and springs. The object is that every governor shall accentuate the action of the others.

As to the effect of the systems of regulation on the weight of the fly-wheel, it is evident that modern engines working with admission on each cycle enable one to use fly-wheels relatively less heavy than was possible with the hit-and-miss type. We have analyzed elsewhere the effect of double action and multiple-cylinder arrangement on this factor. The weight of fly-wheel is, moreover, dependent on the class of service which the engine is required to perform. When driving electric generators the rotating masses of the dynamo may render sufficient kinetic energy

for securing a steady turning moment, and no separate fly-wheel may be required. For ordinary industrial purposes a cyclic regularity of $\frac{1}{25}$ to $\frac{1}{30}$ is sufficient. For electric lighting by direct-current generators the degree of irregularity should be less than $\frac{1}{50}$ or $\frac{1}{60}$; while for driving alternating-current generators in parallel it should be as low as $\frac{1}{125}$ and preferably less. The formulas for determining the weight and dimensions of fly-wheels for different types of engines, having regard to the purpose to which they are intended, can be found in any of the elementary works on gas-engine design.

Arrangement of Cylinders

Until a few years ago there was a tendency among builders of large gas engines to increase the size of single-acting four-cycle units up to 500 h.p. and more in one cylinder. The drawbacks of such arrangement consist chiefly in the difficulty of properly balancing the kinetic forces due to the immense weight of the revolving and reciprocating parts, and in the necessity of adopting extra-heavy fly-wheels to produce uniformity of turning effort for dynamo drive, which increases friction, weight, and first cost of the plant. That the latter factor is of no little consideration will be best seen from the fact that, for a coefficient of regulation of $\delta = \frac{1}{20}$, the required weight of fly-wheel — assuming a rim velocity of 20 m. (65.6 ft.) per second — must be at least 50 kg. (110.2 lb.) per brake horse-power. Hence a 500-h.p. single cylinder four-cycle engine would have to have a fly-wheel weighing 25,000 kg. (55,115 lb.), about one-third of the plant weight. For a coefficient of regulation $\delta = \frac{1}{75}$, which is necessary for ordinary dynamo drive, the fly-wheel for the same motor, with the same rim velocity, would have to weigh 85,000 kg. (187,390 lb.), and for driving alternators in parallel ($\delta = \frac{1}{125}$), the weight of fly-wheel would rise to 150,000 kg. (330,690 lb.). The absurdity of such practice needs no comment. It is sufficient to draw attention to the difficulty and unprofitableness of building machine tools and providing shop facilities for the manufacture of frames, cylinders, cranks, and fly-wheels of such magnitude.

But even if the limits for an increase of cylinder capacity of the single-cylinder, single-acting four-cycle machine were not

— as they are — rigidly drawn by considerations of workshop equipment and railroad transportation, there are other reasons why such increase cannot be carried too far. The irregular castings of cylinder, jacket, and heads, with their connecting webs, ports, holes, lugs, etc., are subjected to unavoidable cooling strains in the metal which, under the influx of heat, are intensified and may exceed the elastic limit. Hundreds of cylinder castings, representing an enormous capital outlay, have had to be thrown away on this account. Moreover, the fitting of large pistons to the cylinders becomes extremely difficult, and their weight must be supported by the lower cylinder walls, causing excessive wear, leakage of gas, knocking, etc., while lubrication can no longer be effected satisfactorily. Finally, there is the thermal disadvantage that the cooling surface is decreased when the stroke volume increases. Hence, to avoid premature ignition, compression pressures must be reduced accordingly, whereby thermal efficiency and capacity are lowered.

As large gas engines mostly have to work with lean power gases, the disadvantages of considerable clearance volume, low compression and reduced inflammability are especially felt. It is for this reason that gas engines hitherto have not increased in economy with increase of capacity, as steam engines do, but have attained highest efficiency in sizes of 100 h.p. or so, while larger engines showed inferior economy.

The foregoing are a few of the reasons which have forced the designer to abandon the old idea and induced him to create large units by combining several cylinders in various arrangements. It will be of interest to consider the reasons why certain multiple-cylinder arrangements, such as two pistons on opposed cranks, two cylinders on opposite sides of the crankshaft, and others, have been abandoned, everywhere except in England.

Variations in angular velocity can, of course, be limited and perfect balance of the purely reciprocating parts secured by properly computing the weight and velocity of the revolving parts and adjusting them so that their inertia is neutralized; then combining cylinders in proper manner.

Now, when we compare the various multiple-cylinder combinations with regard to the periodic changes of turning movement and velocity change, we find that a single-cylinder

four-cycle engine — assuming a regulation coefficient of $\delta = \frac{1}{40}$, a rim velocity of $V = 20$ m. per second, and a ratio of $S = \frac{pe}{pi} = 0.35$ — requires a weight of fly-wheel, including spokes, of 67.5 kg. per unit of power. Two cylinders opposed working on one crank, or two cylinders side by side with cyclic phases 540 or 180 deg. apart, require 43.5 kg., and three cylinders with cranks at 120 deg. require 15.3 kg. per unit of power. Other conditions being equal, we have for the same types, but working on the two-cycle with doubled capacity: One cylinder requiring 27.1 kg., two cylinders, 5.7 kg., and three cylinders, 2.7 kg., of fly-wheel weight per unit of power.

The transformation of a single-cylinder, four-cycle engine into a double-acting engine improves the coefficient of fluctuation in the ratio of 67.5 to 41.5 — that is, by 38 per cent. When two cylinders are used the improvement is in the ratio of 27.1 to 7.1, or 74 per cent. Finally, if we transform a single-cylinder single-acting four-cycle engine into a twin-cylinder double-acting two-cycle engine, or into a twin-cylinder double-acting four-cycle tandem engine, then we can reduce the weight of rim per unit of power — assuming identical limiting conditions for change of angular velocity — in the ratio of 65 to 1.

Adding a second cylinder in tandem combination to an existing double-acting engine will double the capacity of the latter, and improve the angular velocity variation by 20 to 25 per cent. These are some of the practical considerations which lead to the adoption of double-acting engines.

It is obvious that any combination of single-cylinder engines for purposes of creating high-power units will show the faults of its elements in intensified form. There is an arrangement which has been in special favor with engineers for the last few years, namely, the double-opposed type with four single-acting cylinders working on two cranks set 180 deg. apart. Four cylinders and pistons, rods, eight valves, four igniting mechanisms, etc., are necessary in this combination, the shaft and bearings becoming complex, the plant weight and floor space excessive, especially when blowing engines are to be driven. Moreover, there is the difficulty of access to the interior of the cylinders, and, last but not least, with a given direction of rotation the guide pressure in one set of cylinders counteracts the piston

weight, hence knocking is likely to occur at each change of the pressure phase.

That the single-cylinder, single-acting type of engine, and of course any multiple-cylinder combination of it, is, for large power plants, the most unprofitable construction as to size, weight and cost, can best be seen when we investigate the efficiency with which the reciprocating and revolving masses of metal in such an engine are utilized; or, in other words, when we compare the necessary weights and dimensions of such driving parts with the maximum capacity which such an engine is capable of producing under normal conditions. The bad effects resulting from an increase of cylinder dimensions and those resulting from the use of enormous fly-wheels have already been considered. An examination of the driving forces as the limiting

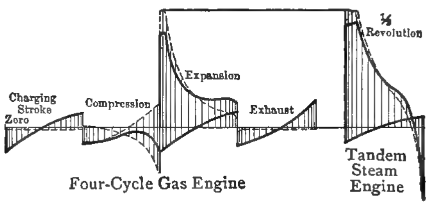


Fig. 21. — Effective Pressure Curves for Four-Cycle Gas and Tandem Steam Engines (Riedler).

condition in the design of high-power units, and their relation to steam-engine practice, will serve to complete the investigation.

When the effective or net pressures at the piston and the turning forces acting on the rod, crank, and shaft of a gas engine are compared with the corresponding pressures and forces in steam engines, they show a greater similarity than one is inclined to believe. The accompanying series of diagrams, Figs. 21 and 22, presented in an address of Professor Riedler before the Society of German Engineers, clearly illustrates this fact. Fig. 21 shows the effective or net pressure curves plotted for a four-cycle gas engine and a tandem steam engine, under the assumption that the maximum piston pressures of both are equal. Fig. 22 is the turning-effort diagram for both engines.

While the effective piston pressures and turning forces of the steam engine are slightly higher than those of the gas engine, it

will be seen that the increase and distribution of pressure in both types — the gas engine working with high compression and early ignition and the steam engine with high speed and high compression — in modern practice show very little difference. This indicates clearly that the design and computation of the driving parts must necessarily be based on the same principles which have been so successfully applied in steam-engine practice.

Now taking the gas force at the piston as the limit of practical construction, Fig. 23 will give an idea of the mutual relation of those forces which govern the dimensions of driving parts in three different types of engines, namely, the three-crank steam engine,

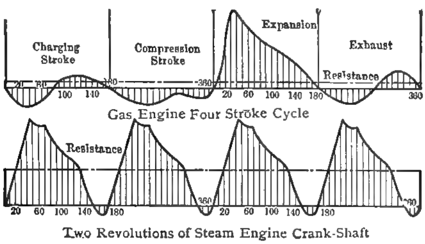


FIG. 22. — Turning-Effort Diagrams for Four-Cycle Gas and Tandem Steam Engines (Riedler).

the blast-furnace gas engine, and the Diesel oil engine. Fig. 24 supplements and confirms my views expressed in the discussion of single-acting, multiple-cylinder combinations. Assuming as before a maximum gas force at the piston of 300 tons, the limits of capacity for the three types are shown, together with the effective forces acting on their respective driving parts, when assuming equal output for all three.

It will be seen that a single-cylinder, single-acting gas engine requires 5.32 times the gas force on driving parts required by a single-crank steam engine, while its capacity is limited to 800 h.p. as a maximum. This, however, is the most favorable case. Compared with a three-crank steam engine, twenty-four times the amount of driving force would be required for the same output, while the maximum capacity of the single-acting, single-cylinder gas engine would still be limited to 800 h.p. The double-acting tandem gas engine requires six times the amount

of gas force at driving parts that is necessary to secure the same output in a three-crank steam engine, while 3200 h.p. is the maximum that may be developed by such a combination.

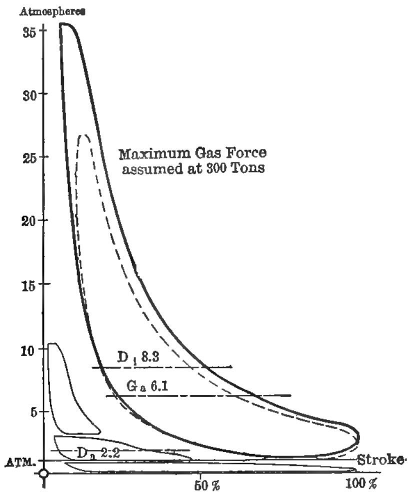


FIG. 23. — Pressure Diagrams for Three-Crank Steam Engines, Blast-Furnace Gas Engine and Diesel Oil Engine (Riedler).

A twin-cylinder tandem gas engine would require only three times the amount of driving force required by a three-cylinder

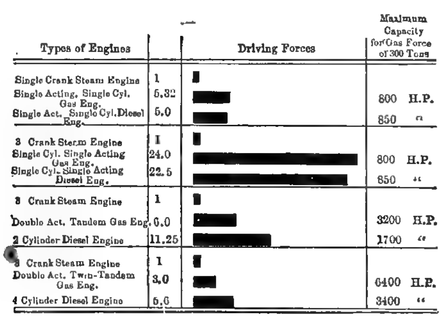


FIG. 24. — Diagram Showing Driving Forces in Various Types of Engines (Riedler).

steam engine and its maximum capacity would be 6400 horse-power.

The single-acting, single-cylinder four-cycle engine is therefore absolutely unfit to serve as a high-power unit, as its elements and driving parts go on increasing in a cumulative ratio without allowing efficient utilization of their masses, while the maximum capacity of the type is kept below the limits of modern requirements.

The superiority of the new combination over the old will become apparent upon comparing two engines, built by the same factory, one representing the old and the other the new tendency in gas-engine design. The comparison is as follows:

Single-cylinder four-cycle engine, old type: Gas force on driving parts, 300 tons; capacity, 700 b.h.p.; revolutions per minute, 94; weight, 215 tons.

Double-acting tandem engines, new type: Gas force on driving parts, 100 tons; capacity, 800 b.h.p.; revolutions per minute, 125; weight, 100 tons. Gas force on driving parts, 200 tons; capacity, 2000 b.h.p.; revolutions per minute, 94; weight, 197 tons. (It will be noticed that a double-acting tandem engine, having about three times the capacity of the single-cylinder engine, weighs less than the latter; the cost of manufacture per unit of power is also reduced.)

Referring back to Fig. 14, we find confirmed what was said about the thermal superiority of the new type over the old. The curves *I* and *II* represent the performance of blast-furnace gas engines of equal capacity and built by the same factory, Nürnberg. While the single-cylinder engine consumes 10,362 B.t.u., the new tandem engine attains an economy of less than 8000 B.t.u. per brake horse-power-hour.

That such result is not only gained by thermal improvements on the working process is best seen from the curves in Fig. 15. They show mechanical efficiency for the new type of 92 per cent. against 72 per cent. for the old. All these improvements in floor space, weight, first cost, mechanical efficiency, and heat economy are gained, it is interesting to observe, without any radical departure from recognized theoretical principles of gas-engine design. They are accomplished with the same energy-transforming medium, the same combustion process, and the same cycle. They are, therefore, due to more liberal and careful consideration of those general principles underlying the successful design of steam engines and other machinery.

It is radically wrong to regard the gas engine as a mechanism requiring special treatment, different from any other machine. The engineer who has shown ability in the design and construction of large steam engines will be the best man to be intrusted with the building of a large gas engine, provided that his knowledge be supplemented with the data on the behavior of the various gases when mixed with air, compressed, ignited, and burned in a water-cooled cylinder.

The cut-and-try method which in former years solved a great many problems in machine building, and which baffled scientific investigation, can now, with proper employment of scientific methods, be reduced to a minimum in this country.

In the following discussion of large gas engines, I shall consider such types only as have been evolved and are regarded as standard in German practice. They may, however, be adopted as representative for the entire development, since the leading American and continental builders are all following the course — with minor deviations — which was originally outlined by German engine builders.

IV

THE NÜRNBERG ENGINE

We have already considered how it is possible, by a better utilization of cylinder volume and reciprocating and revolving masses, to obtain satisfactory designs of large gas engines, and how to meet the requirements of balance and turning effort without having to use extra-heavy fly-wheels. It has also been shown that for engines of the four-cycle type the tandem combination of double-acting cylinders is not only the best, but the only practical arrangement to be adopted in modern practice, if floor space does not enter as one of the limiting conditions of design.

From the accompanying drawings it will be seen that the builders of the Nürnberg engine comply with such fundamental requirements, and, as a matter of fact, they deserve the credit of having courageously taken the lead in abandoning the old familiar principles of motor design at a time when there was still a general tendency among gas-engine builders to regard this class of prime movers as something beyond the realm of ordinary machine practice. The Nürnberg engine embodies principles of design which, for the greater part, can be regarded as standard and typical of future construction. It may be mentioned that the largest single-acting four-cycle engine built by the firm in the course of development had an output of 600 h.p., the diameter of cylinder being 1300 mm. ($51\frac{3}{16}$ in.), the maximum piston pressure 270,000 kg. (595,000 lb.), and the weight of fly-wheel, for a coefficient of regulation of $\frac{1}{80}$, 130 tons.

The Frame. — Beginning with the frame, it is known that, with the exception of engines having pistons arranged to work in opposite directions, which will be discussed later, it is impossible wholly to balance the various kinetic forces due to the inertia of reciprocating and revolving masses and the centrifugal forces

and couples resulting from the combination of both, which, through their axial and transverse components, produce shaking and rocking effects and resultant vibrations. Stiffness of frame is the first requirement to prevent rocking of the system, which, when improperly designed, necessitates heavy foundations and strong holding-down bolts, and will never give complete satisfaction.

The construction of frames for large gas engines has undergone three distinct variations. In the earlier types of simplex engines the builders tried to use the Corliss beam type of frame with an overhung crank or what is called in Germany the "bayonet frame," which is so successfully used up to largest sizes in American steam-engine practice. After a short period of experimenting it was, however, abandoned, as with the high piston pressures used in gas engines the single crank bearing proved inadequate for the hard service, especially as the pressure acting thereon is almost doubled, acting as it does on a lever arm of a length equivalent to the distance between the center line of the piston and that of the crank bearing. There are some firms in this country who, nevertheless, have adopted this practice in their latest types. It will be of interest to watch the results of this apparent neglect of continental experience, which so far has never led to permanent success in gas-engine manufacture.

Of course it is understood that conditions of cost and erection favor the adoption of this type of frame in the United States more than anywhere else. The difficulty of bringing three journals — those of the crank-shaft and the one outside for supporting the generator — into true alinement is considerable for unskilled workmen, having little experience with this class of work. The additional price, also, of the second bearing militates against its adoption when a low bid, per unit capacity, is to be made. From the technical standpoint and from that of the power user, considering reliability and durability of service, the second bearing is certainly a good investment, which cannot be cut out, especially not for large and heavy work.

After the failure of the bayonet frame, the manufacturers proceeded to adopt frames running from the main bearings on each side to the extreme ends of the cylinders, with cylinders set down between the girders. The idea was that the system should form one rigid and continuous mass to receive all counteracting

forces and to form a true and common base for the various parts mounted thereon.

There are some builders who still employ this type, as the John Cockerill Company of Seraing, Belgium, but it has now been almost entirely discarded on the continent. The Cockerill frame is formed of two box-girders carrying the cylinder. These girders are joined by tie bolts to others that contain the slides and carry the crank-shaft bearing. The requirement of stiffness and rigidity of frame cannot be met by such construction. It is quite impossible to prevent long frames from bending even while in the workshop, partly because of their own weight, partly from the process of manufacture, while they may be completely twisted out of shape when erected in the power house by tightening the holding-down bolts on an uneven foundation. Long double beams or girder frames are superior to the Corliss type of frame, in that the piston pressure can act equally on two crank bearings, each of which has to be computed as receiving half of such pressure; yet they are heavy with an accumulation of weight where it is least desired, and are difficult and costly to manufacture. They are unsatisfactory as to stiffness, while the distribution of metal impairs the accessibility of parts.

A third solution of the problem under discussion is offered by the Nürnberg engines. The cast-iron frame consists of the two main bearing supports with the crank-case formed between and used as a receptacle for the lubricant, of a guide bed for the crosshead, and of a circular flange to which is bolted the cylinder by a large number of bolts. The frame rests on the foundation throughout its entire length, and accessibility to the crosshead is secured by cutting down the upper edges of the side walls, while strength and fairly central distribution of forces are obtained by connecting the cylinder flange and the main bearings by heavy tie-rods at a considerable distance above the horizontal central plane. This frame forms an absolutely rigid mass, which can be handled with facility in the shop, and allows complete workmanship, adjustment, and finish before transportation.

The circular guide bed and the face of the flange to which is bolted the cylinder are machined on the boring mill without change of position, so that the vertical plane of the flange must be absolutely true with the crosshead guides. The main pressure being directed toward the lower guide, there are only two ledges

provided to keep the crosshead in a true path. The weight of the cylinders and their accessories is taken up by base plates, to which they are fastened so as to allow free expansion longitudinally, or parallel to the center line of the engine. The expansion, however, is very slight, because the efficient cooling of the cylinders and the pistons keeps down the average internal temperature below that of modern steam engines working with superheat.

All constructive details of the main frame can be studied

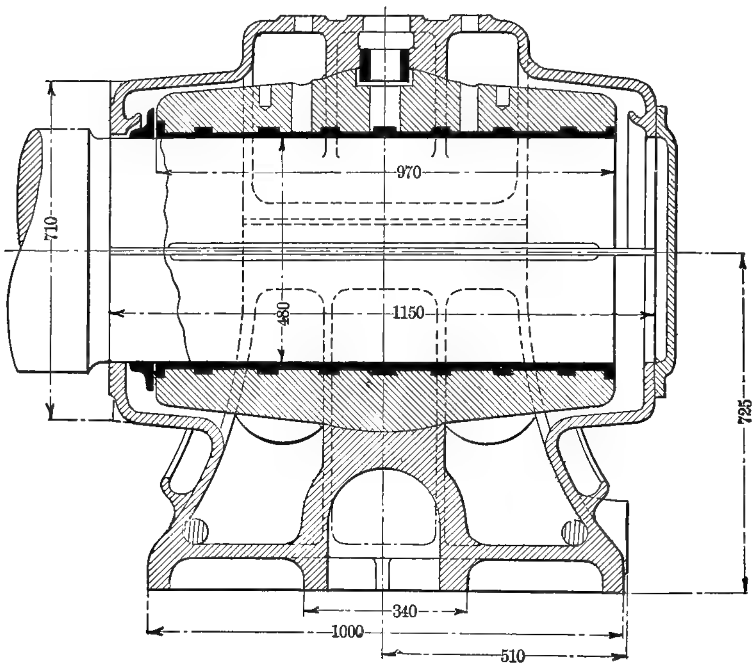


FIG. 26. — Outside Bearing (Nürnberg).

from Fig. 25, which gives a plan view, and longitudinal and cross sections. Since the majority of cuts were reproduced from German working drawings all dimensions are given in millimeters.

OUTSIDE BEARING

When driving large and heavy alternators special care must be taken in dimensioning and erecting the outer bearing, of which a longitudinal section is given in Fig. 26. Since in the earlier types of large gas engines considerable trouble was experienced

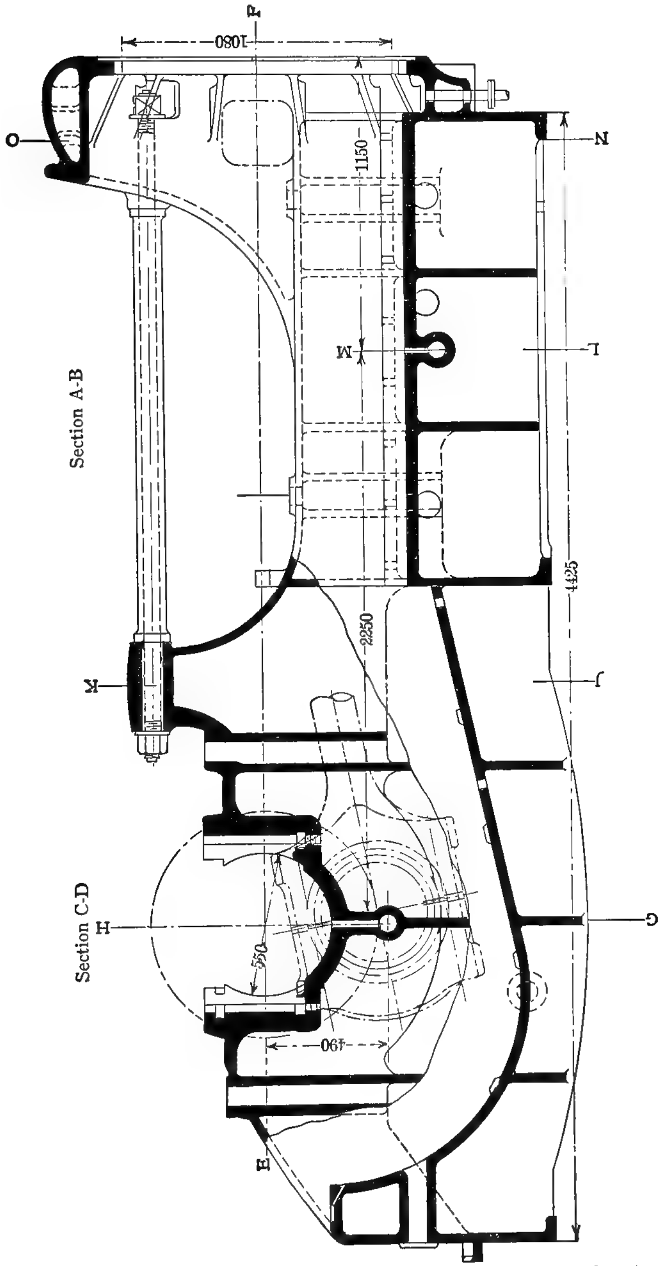


FIG. 25. — Frame of Double-Acting Gas Engine (Nürnberg).

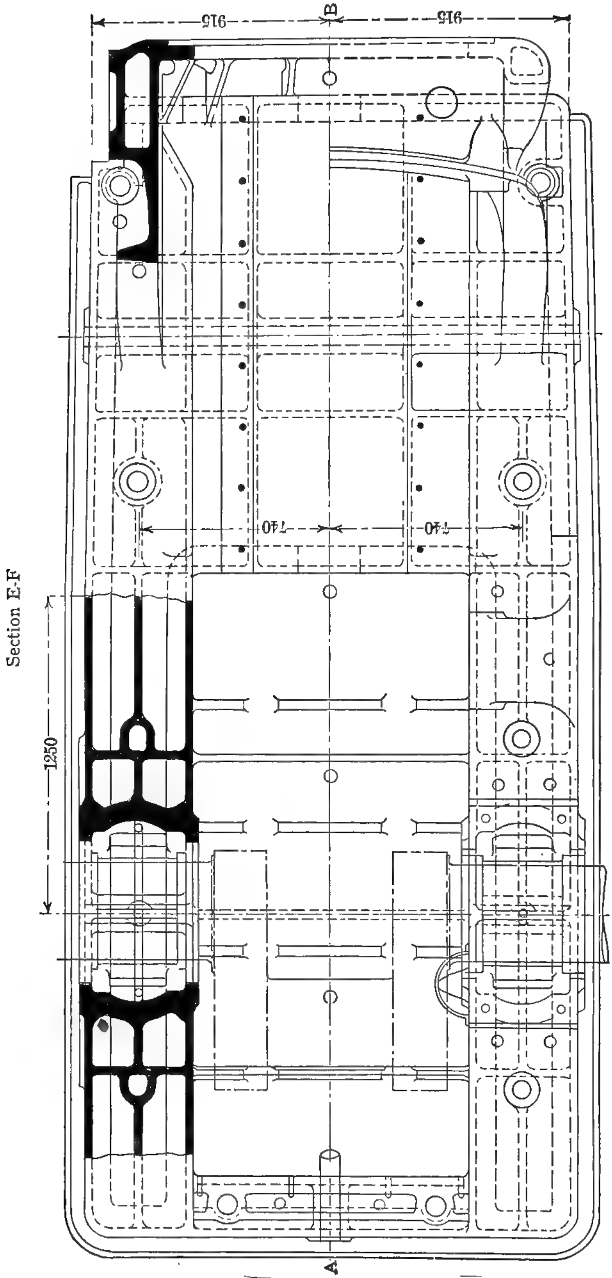


FIG. 25a. — Frame of Double-Acting Gas Engine (Nürnberg).

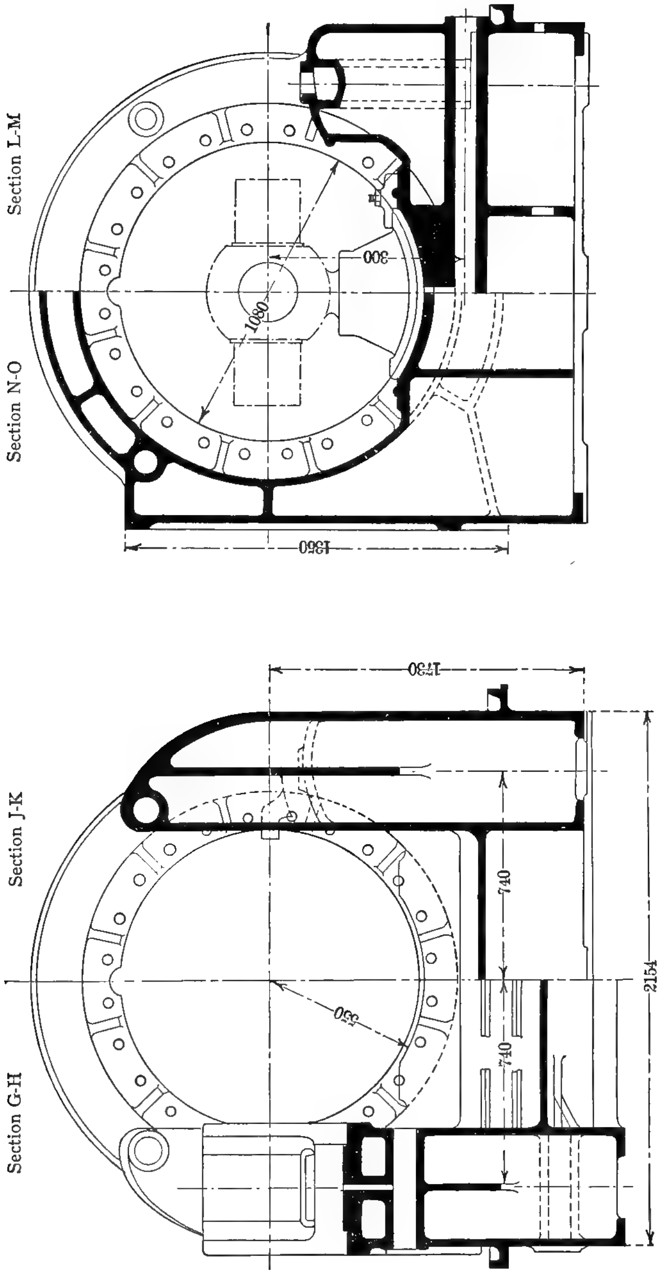


FIG. 25b. — Frame of Double-Acting Gas Engine (Nürnberg).

with overheating the crank bearing, owing to insufficient wearing surface, much care is now exercised on the part of the designer to dimension these parts as ample as consistent with all-round economy. The outer bearing becomes thus very long, up to 3 ft. and more, and provisions must be made that the supporting shells can adjust themselves in tangential direction to the elastic line. They, therefore, have a ball-shaped support, as can be seen from the drawing.

The bending of the shaft by the weight of the dynamo is compensated, also, by mounting the outer bearing somewhat higher than the main frame. When combining engines in twin fashion the two outer bearings are raised by some tenths of a millimeter, in order to secure perfect operation.

The Cylinder. — For calculating the working dimensions of an engine, a mean pressure of 70 lb. per square inch is generally assumed, though in the Nürnberg engine mean pressures of 100 lb. have been recorded, even with lean power gases. The maximum gas pressure employed in modern engines, and that which the metal surrounding the combustion space must be able to resist, may be put down as 450 lb. per square inch. With a sufficiently high factor of safety or sufficiently low initial material stress this will give satisfactory results in all normal cases and for all fuels. Abnormal conditions, as, for instance, the development of a momentary explosive wave generating excessive pressure, need not be taken into account with the present regular and clean form of combustion chamber evolved in the design of double-acting engines. The combustion chamber is usually a cylindrical extension of the cylinder and of the same bore, though in some types an annular space is preferred.

The internal pressure generated in the cylinder produces tension on the walls in the axial direction as well as transversely. This may be easily analyzed by properly applying the empirical formulas used for computation of steam-cylinder thickness, provided the wall thickness is only a small fraction of the bore, so that the whole cross section may be regarded as subjected to equal tension. In large gas engines, with necessarily thicker walls, this assumption does not hold true, as there is a greater stress exerted by internal pressure in the inner cylindrical layers than in the outer layers, which difference in stress increases with wall thickness; for this reason, as well as on account of the diffi-

culty of getting dense castings and effective cooling, the wall thickness must not exceed certain limits. The critical condition will be reached when the various material stresses exercised upon the system by heating strains, cooling strains, and active gas forces are coincident in time and direction. This the designer must try to avoid rather by logical consideration than by mathematical analysis, which offers only very limited means by which to form a reliable basis for useful calculation. Even assuming dense castings of uniform composition and distribution of metal, an exact calculation of wall thickness is impossible, for the simple reason that there are too many considerations involved, as, for example, side stresses due to load caused by screwing up nuts on flange bolts, partial reduction of axial material stresses due to the water jacket and connecting webs supporting the cylinder walls, the influence of temperature fall on a single wall, etc.

In single-acting engines of medium size it has been the practice, heretofore, to cast the cylinder and jackets separately. The cylinder then assumes the simple form of a thin shell which is sometimes provided with external ribs for strength, a practice that cannot be recommended, and is fitted in the breech end of the jacket so as to allow for free expansion in the axial direction. That such expansion cannot be neglected, especially in long-stroke engines, may be seen from the accompanying table. Assuming the medium jacket temperature to be 20 deg. C., and that of the cylinder 100 deg. C., there exists a difference in temperature of 80 deg. C., and we have:

For cylinder length of	20	30	40	60	80 in.
An axial expansion of	0.018	0.026	0.035	0.052	0.07 in.

Besides facilitating expansion, this cylinder construction offers the advantage of permitting the choice of especially suitable material for the cylinder proper; moreover, its reboring becomes easy and the casting of the jacket is simplified. For large work the fundamental requirements of stiffness and location of valves make the casting of the cylinder and the jacket in one piece advisable. When wide water spaces are provided, the system having a symmetrical form, it is practicable to control the expansion without weakening the construction, by separating the cylinder and the jacket or splitting the latter peripherally, which is often done. Yet we find a considerable number of makers

using jackets consisting wholly or partly of sheet iron, and these, up to the present time, seem to give satisfaction. Another novelty is to make the outer cylinder walls thicker so as to fit them for transmitting heavy stresses, while the inner walls are kept thinner in order to increase the cooling influence of the jacket water.

Recent investigations made by Reinhardt to determine the influence of high initial temperatures on the breech end of gas-engine cylinders by means of careful mathematical analysis, which, with certain limitations, can be applied also to the wall system in general, have brought out the following results:

1. For a given range of temperature the strains in the metal resulting from the difference in temperature of the two sides of a single wall are independent of the thickness of the wall. They depend entirely on the product of the coefficient of expansion × the modulus of elasticity. With curved surfaces the radius of the curve is important, conditions being most favorable when its length is maximum.

2. The strains resulting from unequal heating of the breech end, or from the average temperature differences of the single walls, depend to a large extent on the elastic qualities of the whole system, all strains — especially those caused by simple compression and tension forces acting in the axial direction — being reduced when elasticity is increased.

3. The strains mentioned in the preceding paragraph are directly proportional to the thickness of the walls, the stresses due to axial forces following a square and those due to bending a linear equation. The thickness of the walls must, therefore, be reduced to the minimum compatible with other requirements.

4. Internal ribs and tubular connections are apt to diminish considerably the elastic qualities of the system. They must, therefore, be designed so as to be able to yield to stresses tending to deformation.

5. For two different materials, as, for example, cast iron and cast steel, having approximately the same coefficient of expansion, the sum of all stresses is directly proportional to the modulus of elasticity. Hence by making a cylinder, or part of it, from cast steel instead of cast iron, the factor of safety is not considerably increased.

From the foregoing it is evident there are, besides the un-

controllable cooling strains in the casting, three different causes producing strains in the wall system, namely, the difference between the temperature of the cylinder wall and that of the jacket; the difference between the temperature of the inner and outer layers of the wall of the cylinder barrel proper; the internal pressure produced by combustion within the cylinder. The effect of the first cause is to produce a tension stress acting in the longitudinal direction in the jacket, and a compression stress of equal magnitude, acting parallel to the first, in the cylinder barrel. The end flanges and all pockets or lugs connecting the cylinder and jacket barrels are, from the same cause, subjected to a bending stress, the bending moment in each part being equal to the product of the proportion of the force acting in the direction of the cylinder axis × half the hight of the flange. In other words, the bending moment is directly proportional to the hight of the flange. Its influence on the cylinder walls is so small that it may be neglected. The effect of the second cause, which cannot be reduced by careful design, is that there are produced tension stresses in the inner cylindrical layers and compression stresses in the outer ones, which may lead to excessive material strains when the difference in temperature exceeds certain limits. The tension stresses produced by the combined second and third causes in the walls of the inner cylinder are partly compensated by the compression stresses produced by the first cause. This is about all that can be said with certainty about heat relations in cylinder walls in general. To draw any other conclusions is mere guess-work.

I will now proceed to study the cylinder of the Nürnberg engine in the light of the foregoing considerations. The cylinder casting is secured to the circular flange of the main frame by means of a large number of stud bolts set into solid metal and located as closely together as possible without interfering with the use of a wrench in setting up the nuts. The cylinder casting is provided with a vertical annular flange which fits into the circular opening of the flange on the bed frame and insures perfect alinement between the axis of the cylinder and the guides.

Figure 27 gives a longitudinal and a cross section through the cylinder and shows the symmetrical form of the cylinder and jacket casting, with the large water space between the inner and

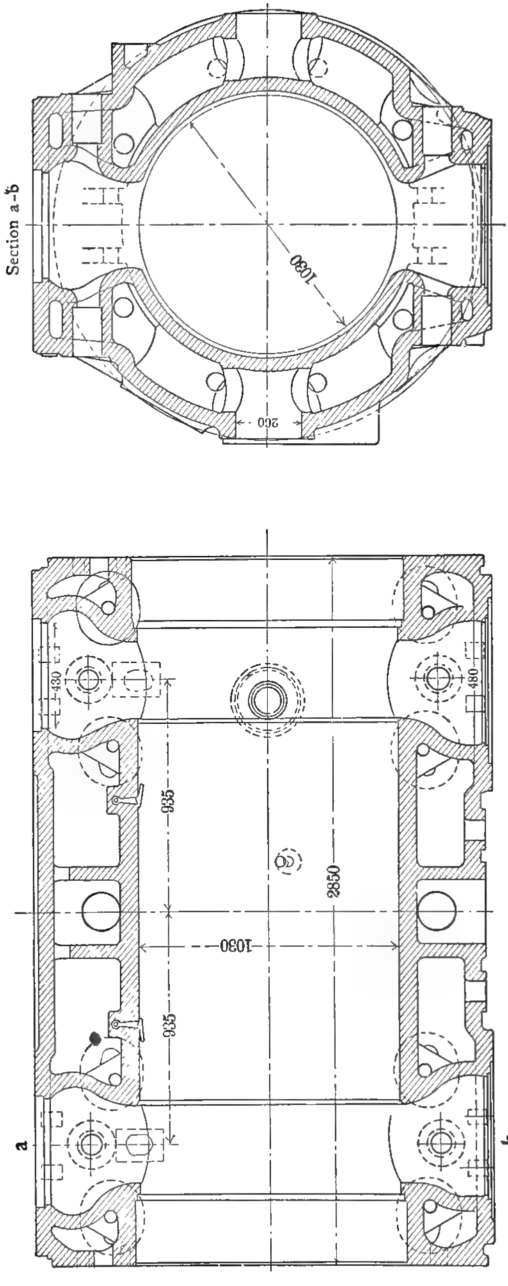


FIG. 27. — Cylinder of Double-Acting Gas Engine (Nürnberg Patent).

outer walls. The axial stresses are transmitted equally to the cylinder and jacket walls, the bending stresses in the end walls being kept within reasonable limits, as the stresses due to the expansion of heated parts, though acting on a long lever arm, may be determined beforehand. Large spaces and walls of uniform thickness facilitate coring, prevent cooling strains, and give dense castings. Several holes are provided for inspection and the removal of sediment. The flow of water is so directed that circulation is quickest on the hottest parts, and the formation of air pockets is therefore avoided. Four valve pockets with curved walls form passages for the inlet and exhaust valves at the top and bottom of the cylinder ends and connect the cylinder and the jacket together at four points, while two lugs on the side of each end strengthen the wall system in the horizontal plane. The curved edges connecting valve pockets and cylinder should have ample diameter, regardless of cost, so as to reduce the stresses at this weak point which is most liable to fracture. Four more lugs, symmetrically distributed, serve for connection around the middle of the cylinder, being located in a plane vertical to the cylinder axis.

The jacket wall serves to carry parts of the mechanism, the valve boxes, the secondary shaft, etc. Its weight was supported, formerly, by wide lugs resting on tubular frame plates parallel to the cylinder axis. In the latest types these supports have been abandoned, so that the cylinder forms an absolutely symmetrical casting, being supported only by the end flanges. Better access to the exhaust valves is therefore secured. The arrangement of core and inspection holes, as well as the connections for water circulation, may be studied from the accompanying drawing, Fig. 28, which shows the combination of the cylinder with piston, cylinder heads, and valve cages.

A few words may be added on the practical lessons which were obtained in the construction of cylinders from Nürnberg engines after doing continuous service for a number of years in German iron and steel works.

Regarding ribs, it was found that stiff longitudinal ribs should not be employed at all, and that everything which is apt to make the wall system inflexible should be eliminated. The settling of sediment or dirt in corners and other places of the water space must be strictly avoided, since it has been proved time and again

that the majority of fractures of cylinder walls have been due to insufficient cooling at such places.

Regarding valve pockets, it is known that they were originally adopted with a view to reducing thereby the total length of cylinders, also to prevent valve disks, which may eventually be torn from the stem by the constant hammering, from falling into the cylinder and working destruction. It was found that these reasons were not sound. Obviously, the reduction in total length of cylinder is inconsiderable. Moreover, no trouble has so far been experienced from broken valve disks, at least not in four-cycle engines, where the hammering and wear of inlet-valves is only

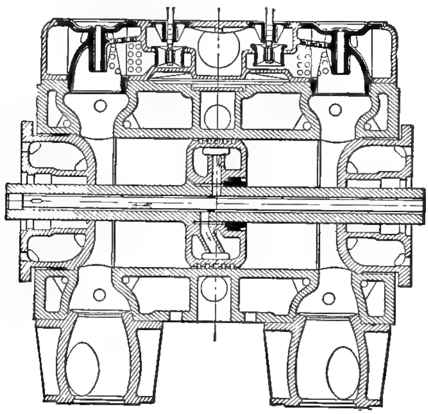


FIG. 28. — Combination of Cylinder, Piston, Cylinder Covers and Valve Cage.

half as bad as in engines of the two-cycle type. The points which are most delicate in the cylinders of large gas engines are located in the immediate vicinity of the pockets and lugs connecting the inner barrel with the outer wall. Therefore, there should be as few rigid connections between the two parts as possible.

Such parts as appear weak can be suitably strengthened by means of tie-rods or compression bolts. These bolts were originally employed for holding together the walls of cylinders that had cracked and had been repaired. Now they form an intrinsic part of the construction and are provided for in the design.

The idea is to produce initial pressure stresses in a longitudinal as well as in an axial direction, which counteract the tension forces that occur when the cylinder gets heated up, thereby

strengthening the wall system. The question remains whether the reduced efflux caused by these bolts is less harmful. Similarly, contraction rings may be put around dangerous parts of the system. These rings should either be forged or rolled with a larger diameter. All internal corners, edges or projections in the combustion chamber must be avoided. They are harmful both as to the life of the cylinder and to causing premature explosions.

Regarding internal temperatures, Reinhardt says that in the older types the inner surface of the rigidly connected parts was exposed through the whole of its length to the highest temperature at each explosion, while modern cylinders are much better in this respect. With the latter this can be explained by the fact that, because the cylinder covers project into the cylinder at both ends as far as the surface of the joint, the inner cylinder walls are cooled, both from without and from within (by the cooled walls of the cylinder covers), and further, that the middle portion of the inner walls, or rather the working surface of the cylinder, does not generally reach these high temperatures, and the whole working surface is passed over by a cooled piston. The latter effect, however, cannot be overestimated, since in modern engines the piston is suspended on the rod and there is no direct contact between barrel and cylinder walls except such as is transmitted by the packing rings.

Nevertheless the average temperature of the inner wall remains considerably lower than was the case with the older cylinder heads, and the design is also much more trustworthy. Many makers have ceased to cast the valve chambers, which, with the inner cylinder, form one piece, together with the outer casing, and thus increase security of construction. This is the reason why, during the last few years, few instances of cracked cylinders have been heard of, and in exceptional cases where they have occurred, those who have investigated the subject are agreed that the cause of the breakage had nothing to do with the construction, but was to be attributed to the pressure of water in the cylinder and to the formation of blowholes and such like causes.

Cylinder Heads. — In horizontal engines having vertical valves arranged on the top and bottom of the cylinder ends, as is the practice in almost all modern engines of German make, the front and back openings are closed by water-cooled heads or covers flanged to the jacket and provided with piston-rod stuffing boxes.

The general arrangement is almost identical with steam-engine practice, with the difference that the heads have to resist higher temperatures and pressures in gas engines and must be designed accordingly.

Cylinder heads are subjected to the uniformly distributed internal pressure which has been assumed to be 450 lb. per square inch as a maximum. Since the ground joint, to be tight, must be under a compression stress greater than the internal initial gas pressure, the heads may be considered as flat circular plates loaded in the middle and supported at the edges. For water-cooled heads, the moment of inertia of the critical cross section must be determined, and from this the moment of resistance found. The hole through which the piston rod passes may be neglected in the calculation, as its connecting wall can be re-

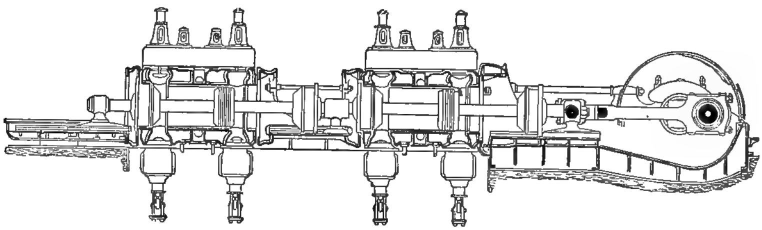


Fig. 29. — Showing Method of Removing Front Heads.

garded as equivalent support, and thus both walls may be treated as solid flat plates connected by a circular web at the edges.

Accessibility of Parts. — The construction of the Nürnberg engine is especially noteworthy for the arrangement of parts with a view to the easy dismantling of the heaviest pieces. Accessibility of cylinders, pistons, and valves is secured by arrangements shown in Figs. 29 and 30. The crosshead proper, made of nickel steel, is so formed as to allow the piston rod, resting on two rings, to be slid through, when the front or crank end of the cylinder is to be examined. Fig. 29 shows how the front heads of a tandem engine are removed to afford access to the corre-ponding valves. The same operation is practicable with the back heads of the cylinder by setting the crank on the opposite (inner) dead center. Fig. 30 indicates the facility with which the pistons are removed by disconnecting the connecting-rod from the piston rod and taking out the latter with the front

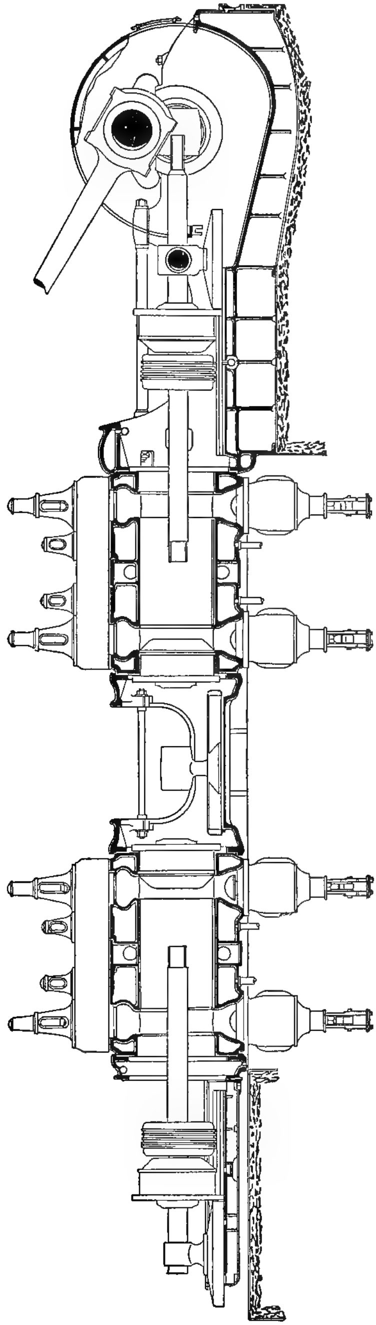


Fig. 30. — Showing Method of Removing Pistons (Nürnberg Patent).

head, while the rods themselves are disconnected at the center in order to liberate the back piston. All inspection work can thus be done by simply sliding the parts on the piston rod, which serves to support them, and without having to remove the crosshead from its guides. Similarly, the distance piece connecting the two cylinders and containing the intermediate piston-rod guide allows inspection of inner parts through a large side opening, where, however, it is suitably strengthened by a heavy tie-rod.

The construction here shown makes it possible to get access to the inlet and exhaust valves and piston rings by simply removing the cylinder heads without having to take off the valve cage and crosshead and dismantle the valve gear. This is a decided advantage, since the exhaust valve, even when properly cooled, is the most delicate mechanism in a large gas engine; impurities, dust, and tarry products settle on the valve seats and the inner faces of the valve disks, and these must be removed from time to time to keep the valves from sticking. The feature of supporting the weight of the pistons entirely on guides is also an important step ahead in large gas-engine work, where the pistons are water-cooled and heavy, and horizontal construction is practically imperative.

Stuffing Boxes. — The construction of stuffing boxes has reached a degree of perfection which eliminates almost all of the various troubles that were formerly experienced in double-acting engines and which, as a matter of fact, have for some time seriously hampered progress.

A type of stuffing box which is in almost universal use in Germany is that of Schwabe, illustrated in Fig. 31. The stuffing box proper is water-jacketed and is contained in a special casing which is provided with a flange for bolting to the cylinder head. There are collars from six to eight in number in which are formed chambers, each containing a cast-iron packing ring cut in three pieces and pressed inward by springs so as to bear on the rod. The front end of the box is built somewhat on the lines of steam-engine practice. Lubrication is facilitated by holes in the middle of the box, to which oil is pumped under pressure. A check valve in the oil passage prevents flashing of the oil.

The stuffing box of the Nürnberg engine is constructed on a similar plan, as may be seen from Fig. 32, with the difference

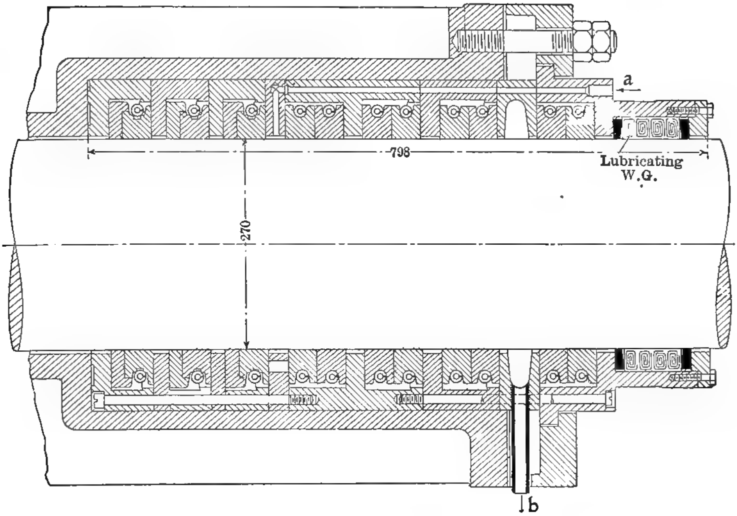


FIG. 31. — Schwabe's Stuffing Box for Large Gas Engines.

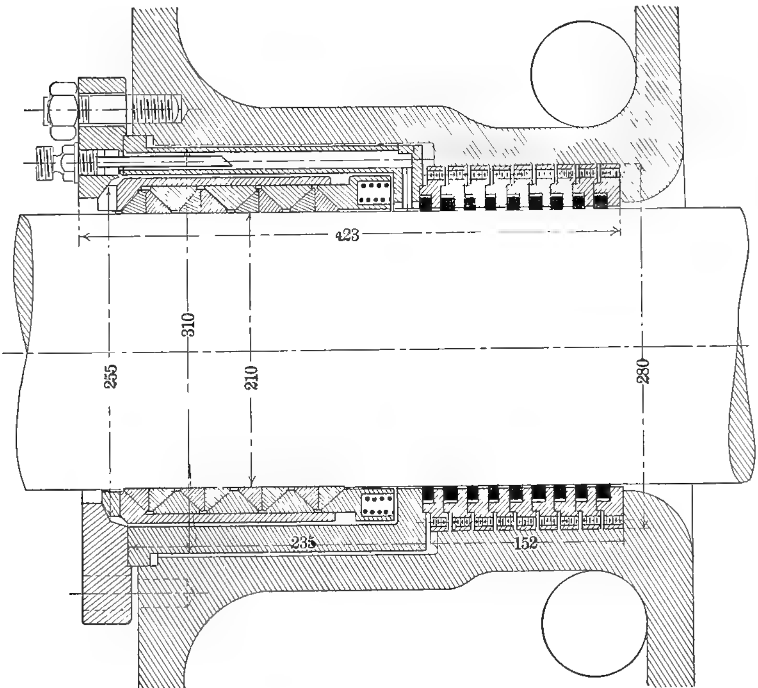


FIG. 32. — Stuffing Box of Nürnberg Double-Acting Gas Engine.

that the packing rings are elastic so as to require no separate springs. In addition there is an external packing effected by babbitted cast-iron rings, which may be tightened by cone-shaped collars, as shown at the right in the drawing. It was said before that in most engines stuffing boxes do not assist appreciably in guiding and carrying the piston rod and piston, the weight of these being supported entirely by guide beds outside the cylinder as already described. With several packings all the rings are made of cast iron. In a few types only those rings situated nearest to the explosion chamber are of cast iron, while the remaining rings are made of suitable white metal. Several packings have an extra front packing; for example, in the Howaldt packing.

Most packings permit a movement of the packing rings in a direction perpendicular to the axis of the cylinder only, a few others allow also a slightly inclined motion of the rod.

Great care must be taken that the cylinder cover is well cooled, that the packing wings are well lubricated, and that they never have to support the weight of the piston rod. This might happen, however, if in the course of time the clearance between the packing rings and the stuffing box became filled with burnt residues. Therefore it is necessary from time to time to remove the packing for cleaning, and for this reason it is advisable to make the stuffing box a separate and easily removable part, and not continuous with the cover. (See Figs. 32a, 32b, 32c.)

Pistons and Rods. — The design of pistons for larger double-acting gas engines involves more careful consideration, owing to the higher temperatures and pressures occurring in the working cycle, than the design of steam-engine pistons. On the other hand, in double-acting gas engines the piston is simpler in design than in single-acting engines, as the side thrust due to gas pressure, inertia, weight of metal and water, etc., is taken up by external guides, allowing adjustment to compensate for wear.

With the exception of double-acting two-cycle engines having exhaust ports, the alternate opening and closing of which at the ends of the stroke governs the length of the piston barrel, the dimensions of pistons depend entirely on conditions of stiffness and weight. The piston must be light to keep down the total weight of the reciprocating masses, and strong enough to resist the gas pressure and temperature effects externally and

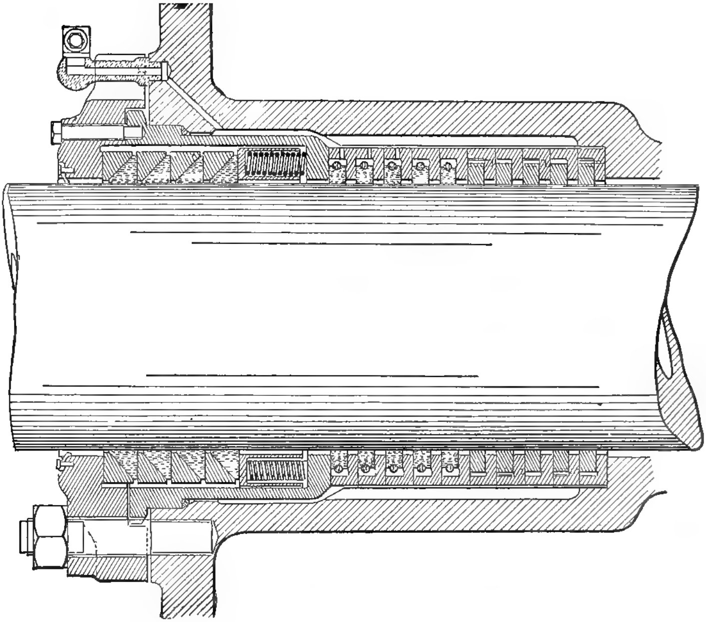


FIG. 32a. — Removable Stuffing Box (Elsässische Maschinenbau-gesellschaft — Mühlheim)

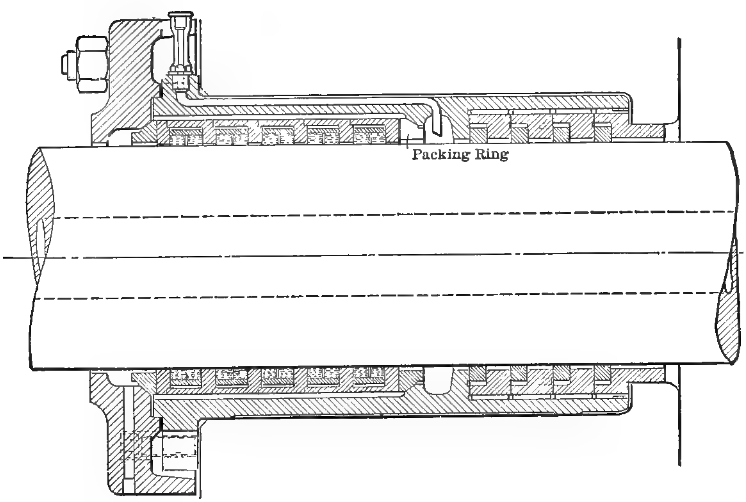


FIG. 32b. — Sieger Stuffing Box.

water pressure acting internally. Its length must be sufficient to allow for a number of grooves, usually five, to receive piston rings, which in modern engines have no other duty to perform than packing.

If the requirement of stiffness is met by internal ribs, their thickness, as well as that of the walls, has to be kept down to obtain light weight and high radiation. It is preferable, though, to employ no ribs at all, at least no transverse ones. To allow for inspection of the piston interior and the removal of mud and sediment (the latter being of minor importance, as the rapid

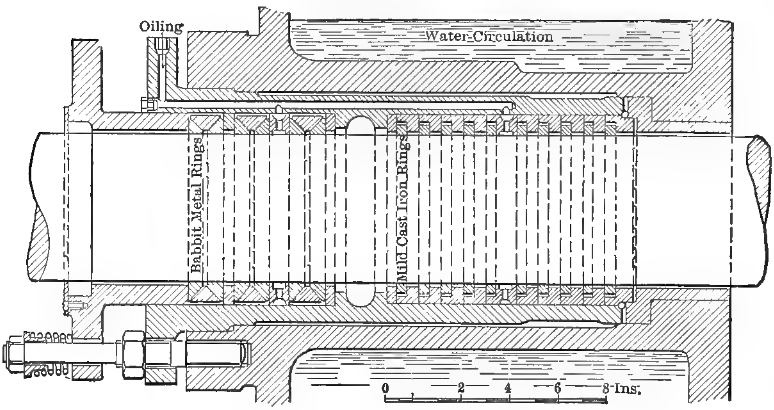


FIG. 32c. — Deutz Stuffing Box.

movement of the piston and water — the mean piston speed being from 800 to 850 ft. per minute — does not favor the settling of sediment, notwithstanding the high temperature), a number of inspection holes should be provided, preferably in the side wall, to avoid the weakening of the head and the burning of the handhole plate bolts. The head ends may be computed as flat plates fixed at the edges and uniformly loaded at the maximum gas pressure. The influence of the rib support is better neglected, as the expansion of the ribs due to heating introduces uncontrollable side stresses which tend to detract from their supporting qualities.

For experimental work it is good practice to make the piston head weaker than the cylinder head, so that excessive pressures will not damage the main structure.

The diametral piston clearance in large double-acting gas engines can, with the employment of water-cooled cylinders and pistons, be exactly predetermined, and is made from 3 to 5 mm. (0.118 to 0.2 in.). The construction is no longer a matter of trial as with uncooled, single-acting piston barrels, which require careful and expensive treatment and show individual peculiarities depending on the rib system, wall thickness, material, etc., and varying with temperature.

Experience in latest practice has obtained that it is not advisable to stiffen pistons with ribs, as these, as is the case with cylinder heads and cylinder covers, are often the cause of fracture. It was rather difficult to find an all-round suitable form of design. According to Reinhardt pistons broke both when they were made in one or more pieces and when they were low and high in tensile strength. With the thicknesses of walls necessary to transmit the energy of the explosion, the initial stresses in pistons are already dangerous, wherefore it is necessary to re-treat the cast-steel pistons after casting. With pistons divided into two parts, great attention must be given to the water-tight joint to prevent leakage of the cooling water, the pressure of which is below 3 to 5 atmospheres (44 to 74 pounds) at the circumference of the piston, as even the smallest leakage prevents the formation of the electric spark necessary for ignition.

Finally, the fixing of the piston on the rod is a very important point. The old-fashioned method of securing the piston to the piston rod by a screwed end and a nut may be employed if the materials of the rod and nut are of very different hardnesses; otherwise, as proved by experience, a slackening of the nut is often impossible. The most practical design for this purpose is certainly that first constructed by Cockerill, in which the two halves of the piston are pressed against a flange forged on the piston rod, by small screws, which can easily be slackened. This construction has now been surpassed by a superior one, built by Schüchtermann and Kremer, of Dortmund, in which the screws that serve to connect the two halves of the piston are located quite outside the cooling water and need not be packed at all.

The cooling of the piston rod and of the piston is now generally so arranged that the cooling water enters the rod at one end and flows out at the other. A flowing back is avoided by a pipe being fitted in the bore of the piston rod. In tandem en-

gines this arrangement is either on each cylinder, or the cooling water is allowed to pass through both rods and both pistons, one after the other. In the first case the cooling water must be at a pressure of from 2½ to 3 atmospheres, and in the second from 4½ to 5 atmospheres. In the engines built by G. Luther, of Braunschweig, the inlet and outlet of the cooling water is arranged on one and the same end of the rod, thus by avoiding the employment of stuffing boxes the construction is considerably simplified.

Similar to the construction of cylinders it is good practice, with pistons, to counteract the continuous change of pressure and tension forces which are exercised internally by the combined actions of the influx of heat and by the weight of the oscillating water, through the employment of longitudinal connecting bolts producing external pressure stresses.

Piston Rod, Crosshead, Crank-Shaft

Piston rods are mostly so turned in the shop that the weight of the pistons and water will bend them into straight lines when mounted in the engines so that there is no increase in friction between the piston barrels and the cylinder walls due to the sagging of the rods. In order to attain this end the piston rod, loaded in this manner, can be turned by keeping the rod fixed and allowing the tool to turn, or the rod is turned with the lathe centers displaced in such a manner that, at the middle point of a line joining the centers of the end sections, the rod has a deviation which is equal to the deflection of the rod when loaded. The material used is best steel, either nickel steel or what we call *Tiegelgusstahl* in German. According to Bonte-Nürmberg the material must have a strength of 60 kg. per square millimeter, allowing 18 per cent. for tension; at the same time it must be very hard in order to secure minimum wear.

Some firms, such as the Körtings, have not taken up the practice, not on account of being afraid that the long pistons are too heavy to be wholly supported by external guides, but because they maintain that the bending of the rod introduces uncontrollable stresses in addition to those produced by heat. As a matter of fact, the upper cylindrical layers of the rod, when it is bent, suffer compression and the lower ones elongation, and these opposite stresses produce axial material stresses in addition to those exerted by the working gas pressure. Another difficulty

arises from the fact that it is hardly possible; and for reasons of economy never practised, to turn the rod according to the true theoretical curve, which is identical with the elastic line. Ordinarily the rod is turned in three sections, which when bent under the weight of the piston cannot, theoretically, lie in the ideal rod axis. The rod is therefore mostly deformed, the two outer sections showing a deviation from the true center line equal to the distance between the straight line and the elastic line, which distance is a constant for any given angle of deformation. This, together with the well-known tendency of thick piston rods to curve when exposed to unequal heating, makes the value of the practice of making the rod curved rather problematical.

The drawings showing the longitudinal section of the Nürnberg engine illustrate well the construction of modern gas-engine pistons and how they are secured to the hollow piston rods. In the engine under discussion the piston is secured in position by internal keys and pressed against a cone-shaped collar by a nut, which in turn is secured against turning. The construction for conducting cooling water to and from the piston is apt to weaken the connection between the pistons and the rod somewhat.

The design of piston rings does not involve anything new over steam-engine practice; the proportions and mode of manufacture may be learned from any of the works on machine design. The same holds true for piston rods and crossheads, which are designed precisely as for steam engines, the only variation in construction being in the provision for feeding water through the crosshead and rod to the piston, while a difference in the computation is introduced in the determination of the maximum stresses by combining the inertia and gas-pressure curves for the proper weight, speeds, combination of cylinders and phases of the cycle. Crossheads should be made adjustable in hight so as to guide the piston and rod with minimum friction and wear through cylinder and stuffing box.

The crosshead of the Nürnberg engine, which is made from nickel steel since it has to transmit a comparatively large bending moment, is peculiar in that the ordinary crosshead pin is absent. Instead, two solid pivots are provided into which the forked end of the connecting-rod engages. Since these pivots cannot be hardened afterward, a material must be employed which is very hard in itself. It should be noted that fillets or

annular grooves should be provided on all those bolts, bars or rods which are exposed to continuously changing and sudden loads, for instance, bolts on crosshead, piston, slide valves, eccentrics and tie-rods. The elasticity or resistive strength of a bolt which has grooves turned in will be much superior for equal shaft and thread diameter to an ordinary one, notwithstanding that the cross section of material is smaller.

In designing the connecting-rods one must take into consideration the influence of the maximum gas pressure, producing tension and compression; that of the inertia of the rod, introducing bending stresses in the rod, and the mutual relations of these forces.

Nor is there anything in the design of crank-shafts which would require special discussion beyond what is known from steam-engine practice. Of course, owing to the high internal pressures occurring in the working process of large gas engines, the dimensions and weights of crank-shafts become very much larger. At the same time the difficulties of the steel works are increased in turning out these monstrous parts. Crank-shafts are forged from solid steel blocks, the weight of which runs up to 65 tons and more per piece, while the weight of the finished crank is about half that much. The reciprocating masses should be balanced so far as possible by counterweights on the crank proper. The shaft should be adjustable in two directions and should run in white-metal bearings equipped with ring lubrication. Two rings, one on each end of the bearing, are preferred to one, as ordinarily employed. They allow a better control of the oil admission, at the same time avoiding a weakening of the bearing shells through perforations.

Valves. — For large gas engines mechanically operated, vertical cone-seated poppet valves must be used. Water cooling of heads, stems, and seats is essential for exhaust valves but not for inlet valves, which are cooled by the incoming fresh mixture. To obtain proper stiffness and effective cooling, the valve head or crown is best given a form approaching a hemisphere, but flat disks will be just as well. The thickness of the valve disk is calculated by considering it as a flat plate uniformly loaded by the maximum gas pressure and supported at the edges.

Exhaust-valve stems when properly guided are subjected merely to compression and have to be computed as resisting —

at the moment of opening — a gas pressure of four atmospheres, as a maximum, acting on the disk. For exhaust-valve stems excess diameter is desirable to allow of reboring; at the same time, better lubrication and cooling are thereby effected, as more heat is conducted to the circulating water. To reduce the stress on the valve stem at the moment of opening, exhaust valves are sometimes balanced. The best way to relieve the valve, in single-acting engines up to 100 h.p. or so, is to provide auxiliary exhaust ports which are uncovered by the piston at the end of the stroke, thus relieving the exhaust valve of end pressure. The valve has then to open only against atmospheric pressure and is brought in

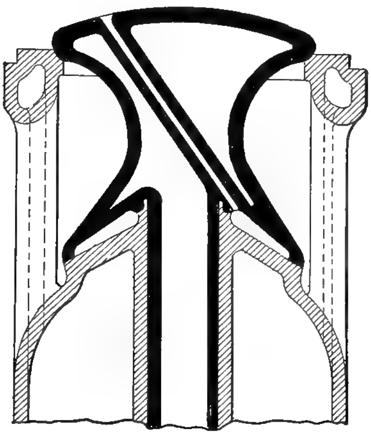


FIG. 32d. — Balanced Exhaust Valve (Pawlikowsky-Görlitz).

contact with comparatively cool gases, the hot high-pressure gases being removed at the auxiliary port.

Double-acting engines, unless provided with long pistons, cannot, of course, profit by such practice, though there are some that use exhaust slots as an auxiliary means. With them a reduction of the stress at the opening is very desirable; therefore exhaust valves are balanced, as is shown in Fig. 32d. The employment of a small auxiliary valve opening ahead of the main exhaust valve so as to relieve the pressure on the latter cannot be recommended as good practice, though it has lately been readopted by a few German builders.

Cooling of the exhaust valves deserves the most careful consid-

eration of the designer. In most cases the introduction of cooling water is so arranged that water is fed to the stem by a flexible rubber tube and flows up to the disk in an annular space between outer and inner concentric tubes, whence it returns through the inner tube and is discharged through another flexible connection. This arrangement cannot be called an elegant solution of the problem. One flexible connection can be eliminated and the

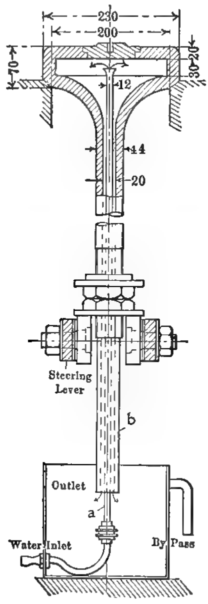


FIG. 33. — Pawlikowsky Method of Cooling Exhaust Valves.

device simplified by conducting water up through a hollow stem to the valve disk, whence it is discharged into the exhaust through an opening on the lower or outer side of the disk, but this also has certain disadvantages.

A system which has found favor with several German builders is that invented by Pawlikowsky-Görlitz and illustrated by Fig. 33. This contains no flexible or swinging connections whatever. Water is conveyed to the valve head through the fixed tube *a*, which extends upward to a point just beneath the top plate of

the valve crown. The water discharged here flows back through the annular space between the valve stem and the inner water tube. The fillet connecting the crown and the stem is made so large that the discharge of the water does not interfere with the valve lift. Güldner, as well as other designers, has adopted this system in his 100-h.p. engine, which is at present the most eco-

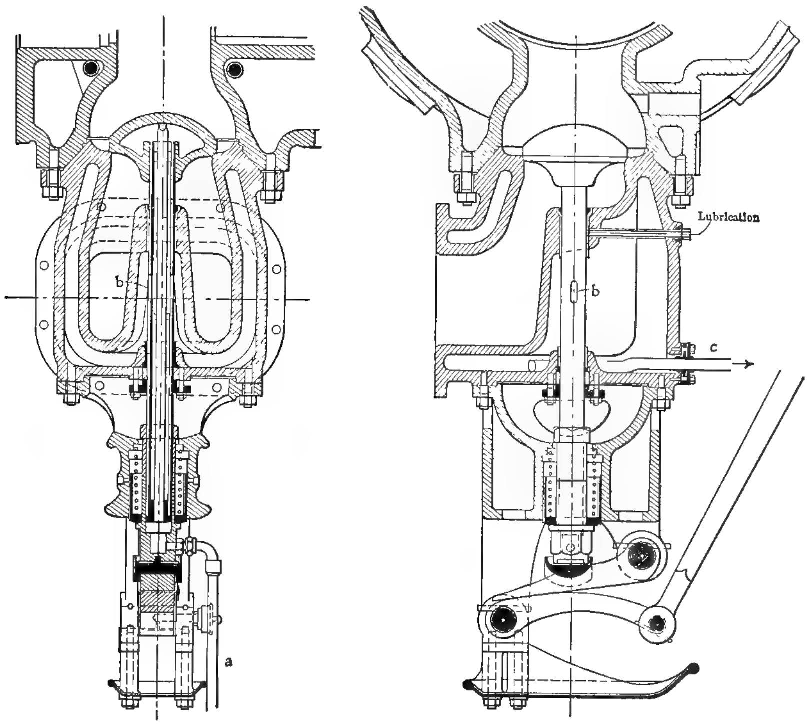


FIG. 34. — Nürnberg Exhaust Valve, Old Type, Showing Cooling, Lubrication and Operating Mechanism.

nomical prime mover on the market, showing a thermal efficiency on indicated horse-power of 42.7 per cent. and on brake horse-power of 34.2 per cent.

Coming back to the Nürnberg engine, Fig. 34 shows the cooling and lubrication of exhaust valves as arranged in older types. A flexible tube *a* conveys water to an inner concentric tube through which it flows up to the valve head; thence it returns through the valve stem, emerging at the opening *b* into the jacket

of the valve cage, from which it is discharged by way of the fixed pipe *c*. Fig. 35 shows a later model which possesses the advantage over the first that the valve and seat can be removed without having to disconnect the exhaust pipe, which is flanged to an outer cage. The arrangement of oil grooves for the lubrication of the stem guide can also be studied from this drawing.

Another device has been adopted in the latest types; this is shown in the drawings of the longitudinal and transverse sections of the 2000-h.p. engine. No flexible or swinging connections are used. The water enters the stem from an inner fixed water box, whence it flows up to the valve crown, returning through

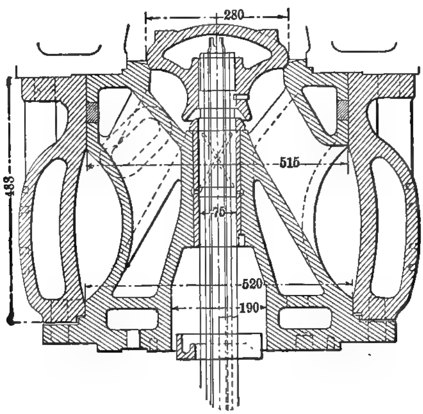


FIG. 35. — Nürnberg Exhaust Valve, Later Construction with Separate Cage.

the bore of the stem and emerging by way of slits in the upper part of the stem into the outer valve cage. This, with good workmanship — which is essential for successful operation to all parts in gas engines — is a clever arrangement. Yet the water-tight stuffing box may lead to hanging of the valve. The discharge of the exhaust is conducted between water-cooled surfaces, and the bearings which guide the stem and at the same time serve as packing boxes are protected from influx of heat by wide water spaces. As has been mentioned already, it is of importance that the valve cage, containing the valve and its seat, can be removed without having to dismount the exhaust pipe. The exhaust-valve chambers belong to those portions of a gas engine which, like the cylinders, cylinder covers, and pistons, are

exposed to dangerous stresses caused by the fluctuating temperatures of their walls, so far as the latter form a single casting. Their design requires, for this reason, considerable care, and, above all, a symmetrical form. It is yet an unsettled question whether the practice, which is employed by some builders, of arranging the exhaust valves not in line with the inlet valves but sideways, in order to facilitate their removal, is preferable to the standard construction.

Combined Inlet and Exhaust Valves. — The idea of simplifying the valve mechanism and at the same time reducing its critical temperature by combining the inlet and exhaust valves is not bad in itself. However, scores of patents have been taken out and a number of devices tried in actual practice without success. Although the combination does away with half of the valves and there are only two valves per double-acting cylinder exposed to high initial temperatures, yet each of these is a very delicate and complex organism, costly to manufacture and difficult to keep in order. Inventors will find it more profitable to devote their energy to other problems yet awaiting solution, such as the overloading, of gas engines, starting under load, reversing, etc., the valve proposition being now quite within the realm of practicability. It may be added that the accessibility of exhaust valves is of the less importance the cleaner the gas and the cleaner the cooling water for the valves.

Valve-closure springs are of the helical type, of cylindrical form and made of steel wire. Their function is to close the valve after it has been opened by the actuating mechanism. In determining the force necessary to close the valve it is not possible to take into account accurately all of the resistances involved in the problem, as there are: (1) Suction pressure in the cylinder, varying from 0.4 to 0.8 kg. per square centimeter (5.7 to 11.4 lb. per square inch) of effective valve surface in engines working with quantity regulation; (2) stem friction, and (3) valve inertia. The first factor is the only one susceptible of exact determination, while the second and third are subject to errors due to the influence of linkage, which can only be guessed at.

As far as mathematical analysis can contribute to the satisfactory solution of the valve problem, designers are referred to those chapters of Dr. Lucke's book which treat of this subject with special care. Furthermore, I deem it unnecessary to dwell

at length on the various relations of valve lift, gas velocity, and piston speed, or on the details of computing the dimensions of valve disks, stems, seats, etc., as there is in these features no divergence between European and American practice so far as the latter is represented in the handbook mentioned. It may be said, however, that in modern practice valve springs are used only for closing the valves proper and not for bringing the mechanism back to its original position. This is left to separate springs, or better, to the positive action of cams or eccentrics.

A good device for reducing the size of the exhaust valve by increasing its tension in proportion to the increase of cylinder suction pressure is shown in Fig. 36. The exhaust valve is controlled by two "wiper" cams *B* and *C*, arranged to work with the usual rolling contact and varying lever ratios so as to decrease the power necessary to start the valve from its seat. The cam *C* is operated by a rod from the eccentric *E* which is keyed on the valve-gear shaft *F*, so that the motion of the valve has a positive relation to that of the engine piston. Only a part of the travel of the eccentric *E* is used to operate the valve, the remaining or "backward" part of the travel being utilized to increase the tension of the valve-closing spring during the suction stroke of the piston. The maximum compression of the exhaust spring takes place at about the end of the suction stroke.

By this arrangement the exhaust valve is relieved of part of the pressure of the closing spring at the moment it begins to rise, the tension of this spring remaining constant at its minimum value the whole of the time the valve is lifted. It is possible to give the valve spring sufficient tension to prevent the valve being unseated by excessive vacuum in the cylinder. The idea underlying this construction is good, but the device as shown is defective in that the part *A* of the valve-controlling mechanism rests on a firm foundation, while the other parts are mounted on the engine, which is subject to vibration. Another drawback is the necessity for disconnecting the ground connection as well as the exhaust pipe before being able to remove the exhaust valve and its seat.

In some engines the exhaust begins about 15 per cent. in advance, and is prolonged a little beyond the finish of the stroke, during which time the admission has slightly commenced. At this juncture the burnt gases have attained a high velocity which causes a powerful suction in the cylinder. The atmospheric

air rushes violently into the explosion chamber, more or less completely sweeping out the burnt gaseous residuals, which would hang in the vicinity of the sparking plug and tend to spoil the ignition of the mixture.

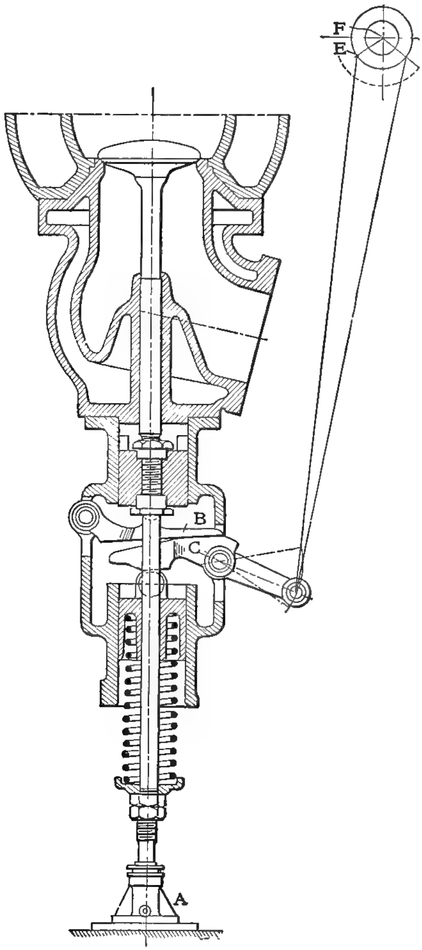


FIG. 36. — Exhaust Valve Giving Varying Spring Tension.

Valve Gear. — The question now arises whether the old cam and roller mechanism is to be further employed in large gas engines, or whether the eccentric is more desirable for future

practice. Cams are cheaper and easier to manufacture and can be made to give a sudden and large valve lift without requiring the interposition of a complex transmission gear. On the other hand, they are noisy, have small bearing surfaces and are therefore subject to considerable wear. By using large cams these difficulties can be avoided to a certain extent and smooth running assured, but when the circumferential speed approaches 1 m. per second, the transmitting forces acting on long lever arms, greater stresses between the roller and cam are at once introduced. Eccentrics have been used in smaller gas engines for a long time without showing any advantages over cams. On the contrary they are costly to manufacture and allow only a limited utilization of their rotary motion unless the travel be made very large; altogether about 15 per cent. of the entire phase may be utilized.

For large work, conditions are somewhat different and the cost of manufacture is not of so much importance. Steam-engine practice has shown that eccentrics are quite reliable, and though the conditions in that field are somewhat better owing to smaller valve lift, lower initial pressure at the moment of opening and shorter duration of inlet-valve opening, yet it is possible, by the interposition of rolling surfaces, to build eccentrics for large gas engines which will have large wearing surfaces, give smooth valve lift with a minimum of actuating force and at the same time eliminate heavy leverages and reduce the play in the linkage system. Thereby, adjustments hitherto left to the erector are avoided, the designer being alone responsible for the working of the valve mechanism. The good results obtained with the valve gear of the Nürnberg and other engines furnish a very strong argument in favor of eccentrics.

In the present state of our knowledge, however, it is not possible to make a definite statement as to the superiority of one mechanism over the other. The fact is that cams, if properly designed, can also, with the interposition of rolling surfaces, be made to run smoothly and without excessive wear on four-cycle engines. They are easily exchangeable and allow of quick adjustment, which is of advantage in experimental work. In two-cycle engines of the Körting type, conditions are very different and usually more complex, because the inlet valve has to be opened within a very small fraction of the stroke, corre-

sponding to a time interval of a few hundredths of a second. In such engines the employment of cams in the ordinary combination with rollers and levers must necessarily prove a failure. The forces acting on the gear rod are dependent on the speed, or rather on the acceleration and retardation of the mass of the gear, and reach such excessive values in large engines that, with the valve-closure spring as used in modern practice, the cams, shaft bearings, and gear wheels are subjected to abnormal wear, so that fracture of the mechanism is likely to occur, even when the best materials are used.

Though it is quite within the bounds of theory to design cams for any given motion which, on paper, will lift the valve safely and by the desired cam curve, the trouble is that the actual cam curve which can be produced with machine tools is far different from the theoretical or ideal. Though the differences may be hardly noticeable to the eye and are often thought quite negligible, yet careful mathematical analysis and practical experience have shown that even the slightest deviation of the actual from the theoretical cam curve may prove detrimental to the whole system. Professor Hartmann, of Charlottenburg, was the first to clarify our knowledge of these commodities.

Under the conditions outlined the only fairly satisfactory solution of the problem thus far attained is that given by a combination of cams and rolling-surface levers, and even then a deficiency in the workshop treatment may ruin the most elaborately calculated gear. It is likely that the builders of two-cycle engines will gradually evolve a new gear system which will better meet the severe conditions limiting the successful operation of large inlet valves at high speed. Fortunately a reduction of the valve lift has proven competible with the successful operation of two-cycle engines, in practice, so that now somewhat higher speeds can be safely employed.

This is what Mr. Reinhardt contributes to the question of cams versus eccentrics:

"The eccentric rods in nearly all designs are combined with roller levers. Thus, in spite of the unavoidable acceleration of large masses of moving rods, and in spite of the pressure on the exhaust valves when opened, the valves are lifted without shocks, and the valve gear works smoothly. The valves opening inward are closed by springs.

"It is obvious that cams must be combined with stronger springs than is necessary with eccentrics, because with the former, in addition to the valve, spindle and roller lever, the driving rod of the gearing has also, as a rule, to be accelerated or moved by springs.

"By the arrangement of a double curved cam, provided with a roller and a counter-roller, a constrained motion of the rod may be obtained both for opening and closing by the roller levers without the aid of spring closure, and by a suitable design of the valve gear the constrainment can be extended just as well with cam as with eccentric, even to the valve by the introduction of buffer springs. The springs have thereby only to endure a compression of a few millimeters. This arrangement as a rule is applied only to the exhaust-valve motion.

"With eccentric-valve motions combined with roller levers, the valve rod and the active roller lever always have to travel a long inactive distance, and therefore, as regards the admission-valve motion, usually require a long spring, having a compressive length equal to the travel of the valve.

"In view of the satisfactory results of valve motions, whether controlled by cams or by eccentrics, no general decision can be taken as to which design is the better for all cases.

"The most important thing is to give the cam the correct form to assure smooth running; and makers of gas engines, guided by experience, understand quite well how to do this, even though the method adopted is said not to be in accordance with the theory of the cam."

Valve-actuating Shaft. — There is not much to say about this part of the mechanism but what is known from steam-engine practice. Conditions differ in so far as the load on the secondary shaft is subject to considerable variation within the course of a single cycle. When the exhaust valve is opened the turning moment reaches its maximum value, and this moment is reversed at the instant of valve closure. This reversal introduces a change of direction of contact between the teeth of the transmitting gear, the variation occurring, of course, once every two revolutions and disturbing the quiet working of the governor. This is practically unavoidable with the present construction of exhaust valves, so that it becomes necessary to mount a fly-wheel on the secondary or valve-actuating shaft which will reduce the fluctua-

tions in rotary torque to a certain extent. Another way out of the difficulty is to drive the governor directly from the main shaft or from a shaft geared to the main shaft but not used to actuate the valves. Both of the latter methods are better than the first named, and will be treated in detail in the discussion of other types of engine.

Regulation is effected in the Nürnberg engine by retarding the opening of the gas valve with decreasing load while the cut-off remains constant under all conditions of load. The opening of the air-inlet valve being constant and that of the gas valve variable as to the time when it takes place, air alone is first admitted and more or less gas is afterward admitted in proportion to the work to be developed. Fig. 37 shows the original construction of governing apparatus. The gas valve is connected to a wiper-cam lever *a* and is opened through the lever *b* by means of the lip on the arm b^1 until the latter is pushed off the end of the valve lever by the roller *c*, whereupon the valve is closed by its spring and damped by the dash-pot *f*. The governor acts through rocker-arm *e* and roller *g* on the curved pallet *d*, the position of which determines the valve opening according to the load on the engine.

Reinhardt maintains that this arrangement is in its action an improvement on the inclined notch gear and is not free from some objectionable back pressure on the governor. To quote:

"It is obvious that the compression remains constant, but the composition of the mixture during the suction stroke is not only very variable with a varying load but also with a constant load. Seeing that at first pure air alone is admitted, and that it is only afterward that the gas is drawn in, the air has acquired an accelerated motion in the inlet pipe, while the gas, which is allowed to enter gradually, starts from rest and has to accelerate; and, in addition, the gas has to flow through an opening, the area of which is continually altering during the period of the opening of the gas valve. The composition of the mixture alters constantly, owing to the opposing influence of the air and gas pressures, and to the alterations of the area of the gas inlet, which occur during the opening of the gas valve.

"The methods of governing and of mixing the gases in newer constructions, in which more stringent specifications for smaller variations of speed are laid down, are much more sensitive to the

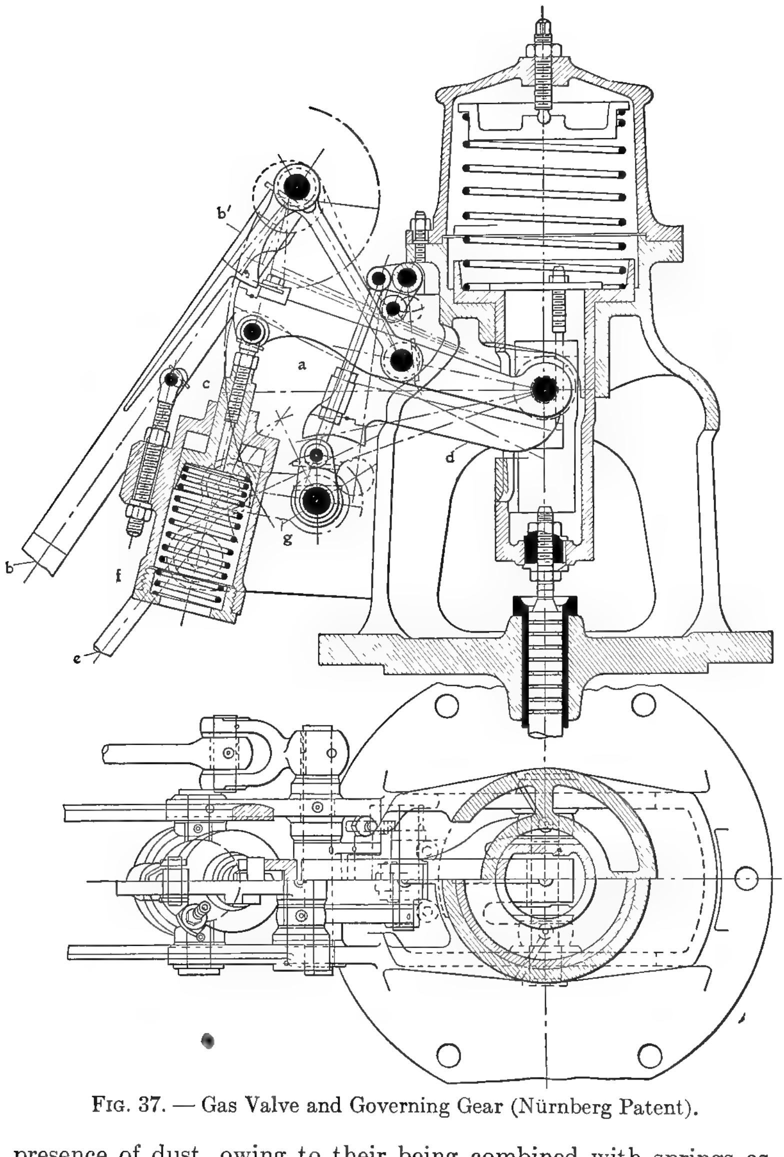


Fig. 37. — Gas Valve and Governing Gear (Nürnberg Patent).

presence of dust, owing to their being combined with springs as delicate as possible, in order to keep the resistance of the governor and back-pressure upon it as low as possible.

"If the spindles or regulating slide valves are covered with a

coating of dust, for instance, the springs are no longer sufficiently powerful to move these parts at all, or at the right moment, irregular working results and disturbances in working. This also occurs if dust is deposited on the valves or slides, the positions of which are regulated by the governor according to the load on the engine. The valves and throttle valves (manipulated by hand) of the gas main leading to the engine are also very sensitive to dust. The dust deposits on them very readily, and renders them difficult to move, and the areas at these places are for the time being unduly restricted, so that the engine does not receive sufficient gas to maintain its normal power. In all the above cases, in addition to the percentage of dust, the percentage of water contained in the gas when admitted to the engine also exercises an injurious effect.

"It is easily understood that moist dust adheres with greater facility to the surfaces with which it comes in contact than dry dust, the greater part of which passes through the engine without being deposited.

"Great trouble is experienced with moist and dusty gas when the engine does not run continuously, but stops working on Sundays, for instance. It may then happen that the deposit of wet dust, which, while the engine is continuously working, does not offer very great resistance to the motion of the valve gear, dries to a hard crust while the engine is not running, and causes these moving parts to become jammed, rendering the starting of the engine impossible.

"The circumstances mentioned above are the result of the gas not being sufficiently purified or dried, as well as of the greater consumption of oil necessitated, and the consequent increase of dirt inside the motor, and, as a matter of fact, are the cause of most of the troubles experienced in working. For this reason, in all new plants, great importance is attached to the effective cleaning of the gas."

Cooling. — In large gas engines, all surfaces exposed to the heat of hot gases must be water-cooled. Hence cylinders, pistons, piston rod, stuffing boxes, and exhaust valves should be jacketed. Igniters are sufficiently cooled by contact between the supporting barrels and the water-cooled cylinder wall. Under such conditions it is sufficient that 33 per cent. of the heat which is generated by combustion shall be carried away by the cooling water. Assum-

ing a heat consumption of 12,000 heat units per hour per brake horse-power, then 4000 heat units must be taken up by circulating water. With water entering at 15 deg. C., and leaving at 50 deg. C., this will necessitate in the neighborhood of 5.3 gal. of fresh water per brake horse-power; 70 per cent. will be used for cooling the cylinder walls, and 30 per cent. for the pistons and valves. This, with proper design, will do for maximum load and for all commercial gases, even those having a high percentage of hydrogen, it being borne in mind that excessive cooling impairs the thermal efficiency. Convection circulation or the like, when the water is allowed to boil in the jacket in order to reduce — by the utilization of the latent heat — the quantity of water needed per hour per horse-power, cannot be adopted for large engines, as overheating and burning of the piston and cylinder surfaces, as well as premature ignition of the gases, will result. Separate circulation should be used for the cylinder, the stuffing box, the valve cases and valves, in order to allow independent variation in the temperature of the respective parts to suit conditions. Thus the combustion chamber may be kept as hot as possible, while the cylinder barrel proper must carry medium temperatures, and pistons as well as metallic packings be still cooler. The main inlet valve should be open to its fullest extent all the time and the water should be regulated only at the respective outlets. For the outlet piping of all water-conducting tubes open or visible overflows must be arranged to facilitate inspection of circulation and temperature of water streams, which form the only controllable indication for the internal conditions. The Nürnberg factory even provides thermometers for the various discharge-water pipes, each of which is controlled by valves, while the water flow to all cooling places may be stopped by closing one valve in the main conducting pipe.

Pistons, of course, require special inlet and outlet piping, as cooling water must be introduced under a pressure of from 4 to 5 atmospheres, by a special pump, while other parts may take water from the city main or be fed from an elevated tank.

In the Nürnberg engine from 2400 to 3200 heat units per brake horse-power have to be carried off by the cooling water. With water entering at 15 deg. C., and leaving at 40 deg. this gives a water consumption of about 30 liters per brake horse-power-hour. When the water is re-cooled the actual consumption of

fresh water can be reduced to from 2 to 0.5 liter per hour per brake horse-power, this quantity being absorbed by evaporation. With a consumption of 30 liters (7.92 gal.) and assuming that the water leaves the cylinder jacket at 35 deg. C., the piston at 40 deg. C., the valve cage at 45 deg. C. (or at 95 at 104, and at 113 deg. F., respectively), then 18 liters ($4\frac{3}{4}$ gal.) are required for cylinders and stuffing boxes, 8 liters (2.11 gal.) for the piston and rods, and 4 liters (1.06 gal.) for the exhaust valves and cages. The cooling of the circulating water in cooling towers possesses, besides a reduction in consumption, the great advantage that there is eliminated the danger of coating passages and metal surfaces with lime scales and deposits, which by detracting from the heat-conducting qualities of the walls of the cooling system may prove disastrous to the working of the engine. The cooling agent must enter the piston on the lower side and leave on the upper to avoid the formation of air pockets. The quality of water used, whether soft or hard, is of little weight compared to boiler practice, so long as it is delivered clean.

The difficulties under which gas engines compared to steam engines have to work can be realized from the difference in temperatures that occur in the respective working cycles. With steam engines a temperature of the superheated steam of 350 deg. C. appears to be the economic maximum, while in gas engines as high as 1800 and even 2000 deg. C. are momentarily recorded. Considering that 500 deg. C. represents the limit of resistance of all materials that can be employed for building these engines, it is evident that efficient and continuous cooling of all heated parts and the prevention of sediment of any kind on surfaces, that might detract from their heat-conducting properties, are points of principal importance for this class of work. How efficiently the cooling process is executed in modern large gas engines is evidenced by the fact that the externally radiating or sensible heat is lower than that of steam engines working with superheat. In a comparison on hand the difference in longitudinal expansion and contraction, owing to the influx of heat, of a steam engine 65.6 ft. long was 0.6 in., and of the piston rod 0.7 in. The corresponding figures of a gas engine of equal length are 0.08 and 0.1 in. respectively.

To reduce temperature all around by injecting water into the combustion chamber, as is done in smaller engines, such as the

Banki, Priestman, and all alcohol motors, is bad practice, for large work. Water may, however, be conducted into the exhaust but outside the cylinder, so that water vapor cannot take part in the combustion process. But then the exhaust pipe must be provided with a drain pipe of sufficient dimensions to allow the water to flow off freely, so that in case of negligence in the use of the water spray — for instance, at the starting of the engine — no water can enter the cylinder through the exhaust valve, and thus occasion its destruction. From temperature diagrams it is possible to calculate approximately the temperatures existing in various parts of the cylinder at certain points of the cycle. Assuming that such a cycle could be followed without external cooling, then there would be the following temperatures inside

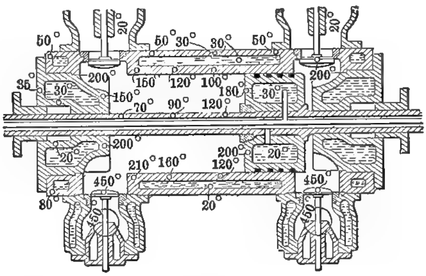


FIG. 38. — Approximate Distribution of Temperatures in Double-Acting Gas Engines.

the cylinder: Inlet valves, 300 deg. C.; exhaust valves, 600 deg C.; cylinder head, 440 deg. C.; walls near combustion chamber, 400 deg. C. on upper and 430 deg. C. on the lower side; walls near the ends of the stroke, 350 deg. C. and 380 deg. C., respectively. No material, of course, can stand such temperatures for any length of time. Effective water cooling reduces the temperatures of the various parts to values about as indicated by Fig.. 38.

The best practice in feeding water to the piston and rod is to conduct the water, through flexible or articulated pipe connections provided with swinging joints and capable of following the to-and-fro motion of the piston, into the crosshead, and, if possible, without change of direction through the rod and piston off to the discharge main by some sort of overflow. This arrangement is shown in Fig. 39. In some types of Nürnberg engines an even superior way is to convey water into the connecting head between

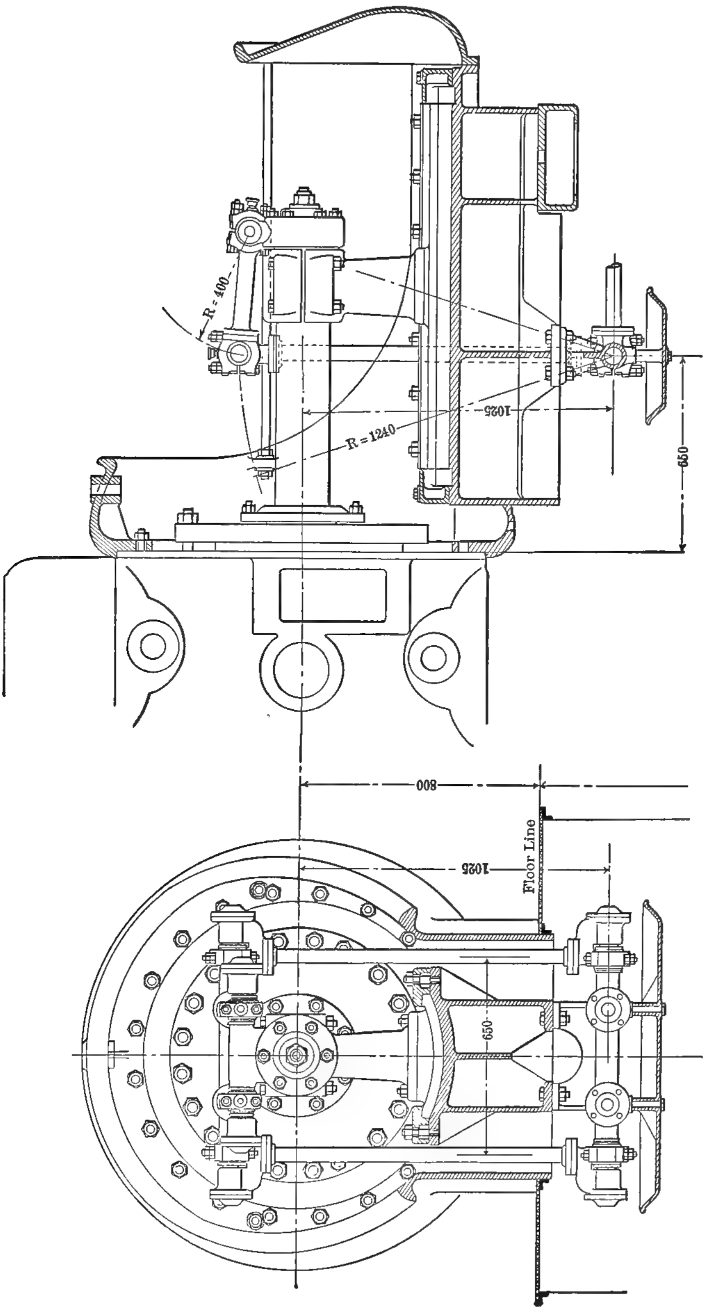


FIG. 39. — Articulated Pipe Connections for Introducing Cooling Water to Piston (Nürnberg Engine).

the tandem cylinders where it proceeds to the head and tail ends of the engine without change of direction, emerging through the crossheads and the external guides into the discharge pipe.

Fixed pipes with telescopic joints require stuffing boxes and an air chamber on the engine to obviate the knocking that would otherwise be produced by the reciprocating movement of the piston and water; such an arrangement is shown in Fig. 40. Altogether this is inferior to the flexible or articulated pipes, yet better arrangements than both may be devised.

Exhaust mufflers ought to have from six to eight times the cubical capacity of the cylinder volume and can be made out of old boiler plates. They should be placed as near the engine as

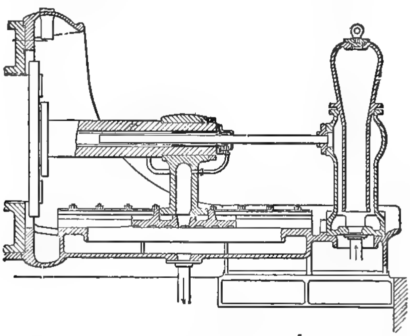


Fig. 40.—Telescopic Pipe Connection for Piston Cooling Water (Nürnberg Engine).

possible, one muffler serving for both ends of a double-acting engine. If cost is not a limiting condition two separate exhaust barrels are superior for the tandem combination, each discharging into the atmosphere, since this will prevent any interference of the varying pressures in the muffler with the internal working processes of the different combustion chambers. From the muffler, the gases are carried off in good-sized underground channels laid in brickwork. Best results will be attained by placing an exhaust fan of the "Sirocco" type, working with water injection, immediately behind the muffler. This will reduce back pressure and noise, and give a clean and continuous exhaust. The extra weight of water and amount of work required for driving the fan are of little importance compared with the advantages gained. With direct injection of water spray into exhaust pipes, the latter

are apt to rust. Provisions have to be made for draining the exhaust piping of the condensing water, and care must be taken to provide for free expansion of the heated pipes. The pipe connecting the exhaust-valve cage and the muffler must, of course, be water-cooled; discharge water from the cylinder jacket may be used for this purpose.

Figure 41 shows the Nürnberg arrangement for damping the noise of the exhaust. The burnt gases are led into an underground

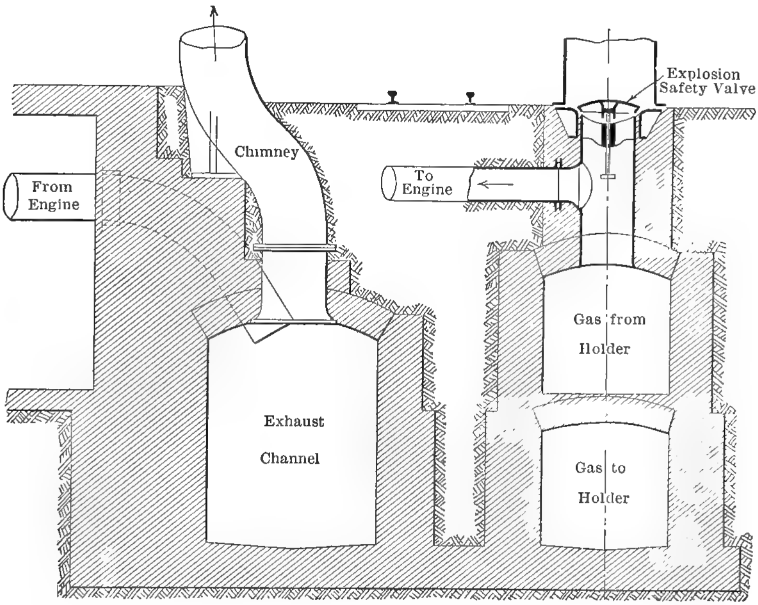


Fig. 41. — Gas Admission and Exhaust Ducts (Nürnberg Design).

channel whence they escape through special chimneys into the atmosphere. The drawing shows also how the fresh gas is conveyed to the gas holder and back to the engine, in superimposed channels, and how explosions — if they should occur in the gas duct — are made harmless by providing a safety valve between holder and engine. The latest method of exhausting employed by the Nürnberg engineers is shown in Fig. 42. The burnt gases are conducted into a vertical barrel having no bottom to it which dips into a water seal about 3 ft. deep. The initial exhaust pressure depresses the water level periodically, thereby securing a nearly constant speed of flow of the discharged gases. In the

upper part of the barrel a grate is provided bearing several layers of stones or rock, which aid to reduce the noise of exhaust in the ordinary manner.

Ignition

Magnetos. — By far the majority of continental firms employ the well-known magneto system, in which the opening spark of an electric current is used to provoke inflammation of the compressed gas mixture. This current is usually generated

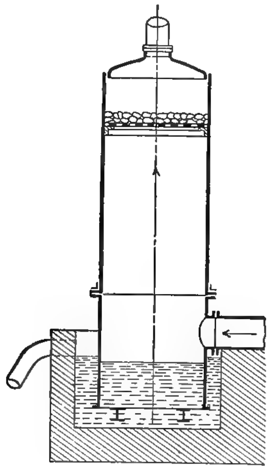


Fig. 42. — Exhaust Barrel with Water Seal (Nürnberg Type).

by oscillating a coil within the field of a permanent magnet, such movement being effected by means of the resilience of a spring which is suddenly released. The apparatus of that type are known under the name of Bosch magnetos. They do away with the necessity for a source of electricity external to the motor. Another method consists in taking the current from a small battery and conducting it in succession through the hammer and the igniting box of the sparking apparatus. This arrangement is employed in the Nürnberg engines, of which Fig. 43 gives the details. The hammer part of the mechanism consists of a coil which turns an iron lever from its rest position by a sudden shock. The hammer is fastened on the axis of said lever and strikes another lever which, in turn, interrupts the flow of current from the hammer

to the box, thereby producing a spark in the combustion chamber. With double-acting tandem engines eight apparatus of this kind

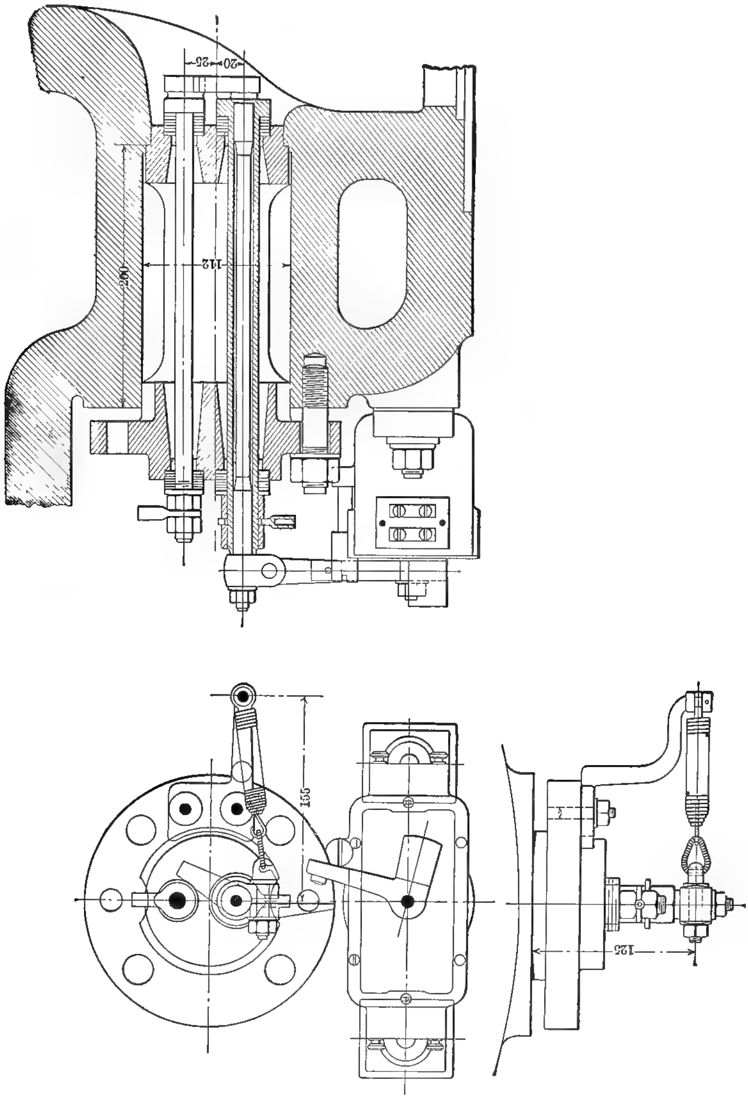


FIG. 43. — Electric Ignition Device (Nürnberg Patent).

are required. The Nürnberg arrangement allows the automatic switching in of the electric current for the different ignition apparatus by means of a contact on the valve-actuating shaft.

At the same time the point of ignition can be adjusted from a central place, and, in case of necessity, the current may be interrupted for all combustion chambers and the engine stopped by turning one lever. The consumption of current is very small; the average for a tandem engine approximates ½ ampere with direct current of some 60 volts. Magnetos are now so universally employed that a detailed discussion is unnecessary.

High-tension Lodge System — Still another method employs induction coils for producing the spark. The latest application of this type is the "Lodge Patent High-tension Ignition," which was invented by Sir Oliver Lodge of Birmingham, England. It is opportune to quote here some of the views of that distinguished scientist on the problem of ignition and internal combustion:

"To achieve ignition the combustible mixture has first to be raised to a certain temperature, a critical temperature locally, and if it ever falls below that the flame expires. Ignition means the raising of a small part of the mixture to such a temperature that combustion takes place, and the remainder of the gas ignites by spreading. The necessary condition of that spreading is that other molecules susceptible of combustion shall be within range of those previously fired. Therefore it is necessary for the spreading of combustion that other molecules should be within such range, for there is a certain point beyond which ignition cannot be spread. But supposing that between the combustible molecules there are inert ones, then, of course, the combustion cannot spread unless some means are taken of bringing each combustible molecule within the sphere of influence of another.

"Usually this is done by having more of them in proportion to the nitrogen and other materials, and subsequently bringing active molecules into closer companionship by compression. Rarefaction prevents ignition from spreading and prevents explosion, but concentration and compression assist it. But as the atoms are not stationary but fly about, the disturbance, — if it lasts an appreciable time, — will assist combustion, because the chances are that one or other of the combustible molecules will come within range of each other, and will be caught by the ignition and will spread it. As the molecules move faster the higher the temperature, high temperature assists combustion and explosion.

"Different gases possess different rates of motion. For instance,

atoms of hydrogen move about four times as fast as the molecules of oxygen, so that any excess of hydrogen will assist combustion. It may be thought that the exact chemical mixture is the best for combustion, but this has been found not to be so. The hydrogen, being the lighter body, its atoms move faster and therefore an excess of that gas is preferable. The effect of diluting the mixture is just the same as rarefaction. Each gas keeps the same distribution as before, as their molecules have different rates of motion, the lightest moving fastest, and the predominance of the lighter constituents favoring the spread of combustion. Dilution with other gases may have a retarding influence upon the combustion. In the weaker explosion the molecules probably go off on the meandering path spreading their combustion, and therefore the explosion will be slow. But with mixtures that are richer the molecules will be closer and more rapid explosion will ensue. If an increased rate of combustion is wanted with the poor mixture, then it must be compressed and ignited in several places. . . . In slow-speed engines a slow-burning mixture may be used with advantage, because a more lasting blow, more of a push, is obtained. The walls of the gas engine are cold, and therefore they put out a flame in contact with them, hence we are bound to have a certain amount of combustible material unburnt. . . . Ignition close to the piston is better, because the initial impulse is given to it more quickly, and the combustion will not have to follow up the piston, as it otherwise would have to do if the ignition took place in the crown of the combustion chamber."

This is what the makers of the Lodge patent high-tension ignition apparatus claim in distinction from other systems:

"The great advantage of using a high-tension current for ignition purposes is that no moving parts are required inside the cylinder, moreover the timing of ignition is accurate and easily adjustable. But owing to the need for very perfect insulation, which is naturally most difficult to obtain inside engine cylinders, a high-tension current has been scarcely practicable as a means of ignition hitherto. Indeed, where producer gases and heavy oils are used as the explosive, it is practically impossible to avoid getting accumulations and deposits of various kinds in the cylinder, which will effectually prevent an ordinary high-tension spark from passing, as desired, at the gap of the sparking plug.

"Sir Oliver Lodge's invention has, however, completely overcome this difficulty, and the high-tension spark produced by a Lodge igniter is of the most remarkable persistency. The secondary or induced current from the coil is stored up by means of Leyden jars, which at the precise moment precipitate an electric discharge of extremely high frequency and suddenness across the gap in the cylinder. This spark, which has been named by Sir Oliver Lodge the 'B Spark,' is of a violent oscillatory character, and of intense white heat. It is not only highly inflammatory, but it is also surprisingly hard to stop; likely forms of obstruction such as soot, oil moisture, etc., have no effect upon it. The spark gap of an ignition plug can be choked up with soot and oil, and the 'B Spark' not only occurs, but blows all out of its path. If the whole plug be put completely under water, the spark passes just the same. The sparking plugs never require to be cleaned, and so continuous runs are quite possible. For engines using blast-furnace gas, this system of ignition has proved quite invaluable.

"Lodge Igniters are now being used with the greatest success on large engines in many places, and the low-tension systems of ignition are rapidly being replaced by the simpler and far more effective high-tension gear. Up to the present, gas engines representing a total of over 30,000 h.p. have been fitted with this ignition."

Further reference to this system of ignition will be found in a later chapter. (Borsig-Öchelhäuser engine.)

The remarks of Sir Oliver Lodge previously quoted are substantiated by the following considerations.

Characteristics of the Explosive Mixture. — Theoretically, ignition must be effected early enough and be so efficient that the whole of the power charge is ignited when the piston reaches the inner dead-center position. Thus the condition of maximum heat development will occur with the minimum cooling surface and in a space which is especially designed to withstand high temperatures and pressures. Purity, calorific value, temperature and compression of the mixture, as well as the position and efficiency of the sparking apparatus, the form of combustion chamber and other conditions, will cause inflammation to spread faster or slower, which phenomenon becomes quite clearly visible on the indicator card, provided the latter be taken on a drum with continuous travel.

In several types of large modern gas engines the point of mixing the gas and air is rather superficially treated, while some designers put very much emphasis on this feature. It is interesting to examine what has actually been done to clarify this question, and which view the serious student of the gas problem is justified in holding.

Gas and air properly mixed in chemical proportions so that just sufficient oxygen is present in the combination to insure perfect combustion will give the highest temperature of explosion which it is possible to obtain. Above and below this ideal condition there is a wide range of inflammability wherein more or less oxygen in the form of air may be mixed with the gas than is necessary for its chemical combustion, so that a mixture of such composition will yet ignite but will burn at a slower rate of flame propagation and, consequently, will not develop the maximum temperature corresponding to its calorific value. If with a certain gas there be mixed about 4.7 times the amount of air that is necessary to establish the condition of chemical balance, the mixture will be that which is theoretically best suited for adoption in gas-engine practice. Theory and practice often differ, and so it is found advantageous to employ in actual practice far more air in the internal-combustion process than is theoretically required. The reasons are threefold: To reduce temperatures all round, to prevent premature explosions which might be provoked by the high heat of compression, and always to supply to the gas, even when poorly mixed with the air, sufficient oxygen for combustion, and consequently to reduce the loss of unburnt gases leaving the exhaust to a minimum.

If one examines by thermodynamic calculation the combustion efficiency of lean mixtures under whatever cyclic conditions they may be transformed into work, it will be found that maximum economy is attained by compressing the weakest mixture to the highest possible degree, but here again one is confronted by an upper limit which is rigidly drawn by the lack of inflammability of such mixtures. Desire for thermal excellence of the working process forces us to approach this upper limit as much as possible, but the decreasing calorific value of the power charge per unit of contents and the decreasing capacity of the engine keeps the actual practice far below this extreme ideal. In average practice it is customary, at normal loads and with lean gases, to

work with a surplus of air of from 10 to 20 per cent. over what is theoretically required; with gases of high heat value, even more air is provided, so that the dynamic medium in the engine cylinder possesses a calorific value of from 44 to 62 B.t.u. per cubic foot. When determining the mean indicated pressures in gas engines with different calorific values of the gas and different quantities of

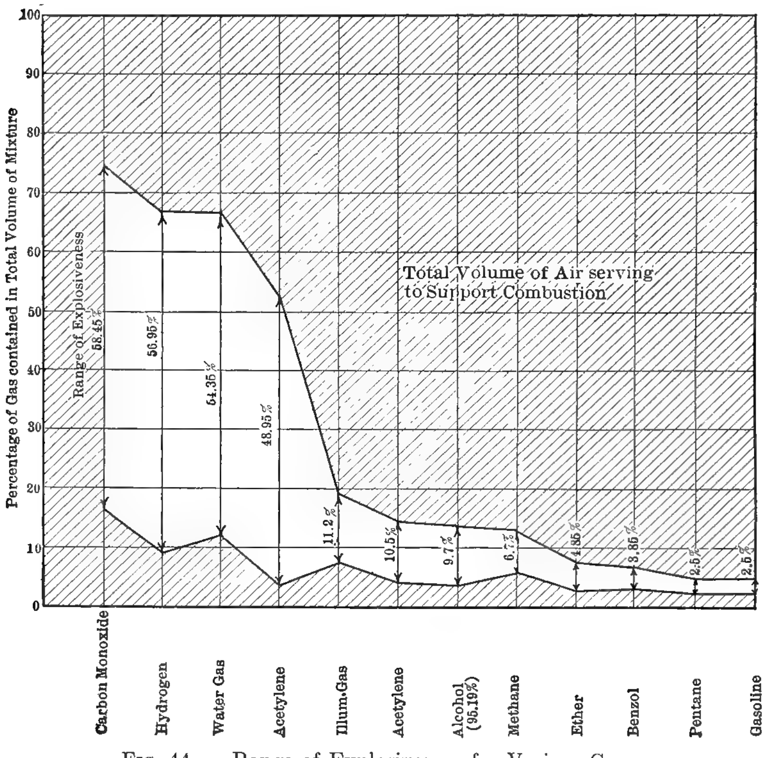


FIG. 44. — Range of Explosiveness for Various Gases.

surplus air, the expansion of the mixture when entering the hot cylinder, and the resulting decrease in weight of charge, must be taken into account.

The range of inflammability varies considerably for the different gases, as may be observed from the curves in Fig. 44, plotted after the results of investigations which were made some years ago by Professor Eitner in the laboratory of the Technische Hochschule in Karlsruhe, Germany. It is evident that the first

four gases have by far the widest range of inflammability. Then follows illuminating gas with one-fifth of the range of carbon monoxide, and thereafter the various hydrocarbons. It is also seen that the quantity of air required to insure inflammability at the upper limit of the range is much smaller than that which is necessary for complete combustion. Now it is obvious that mixtures such as are actually employed in the working of gas engines, consisting not only of the above-mentioned gases, but being diluted with nitrogen, carbon dioxide, steam, etc., must show a slightly different behavior. Their capability to inflame and their range of ignitability will also, to a certain extent, be influenced by conditions of temperature and pressure. Thus it is found that an increase of temperature has a favorable influence on the range of inflammability only of hydrogen and illuminating-gas mixtures, and that carbon dioxide and, therefore, the residual burnt gases have always a harmful influence on the combustion of the power charge.

In diagram Fig. 45 the ordinate distance between the two solid lines indicates the range of explosiveness of various combustible gases when mixed with air at different temperatures, while the ordinate distances between the two dotted lines shows how this range is reduced by admixing with the combustible gases diluents such as are present in the cylinder of gas engines in form of burnt products.

Recent experiments made by Le Chatelier and Boudouard have established the other fact that very lean mixtures of carbon monoxide and air may become inflammable by rapid heating. While at normal temperatures a content of 16 per cent. of carbon monoxide forms the lower limit of the explosive range, it was found that at 400 deg. C., 14.2 per cent., at 490 deg. C. only 9.3 per cent., and at 600 deg. C., 7.4 per cent. of admixed carbon monoxide admixed with air was sufficient. This fact is of special significance for the utilization of producer and blast-furnace gases, which show increased inflammability at the higher pressures of compression.

With all these considerations in mind one can determine which is the most favorable proportion of gas to air for a given set of conditions, and after having settled this question, the next requisite is to keep the composition of the mixture unchanged during the whole of the working time and for all loads. To be

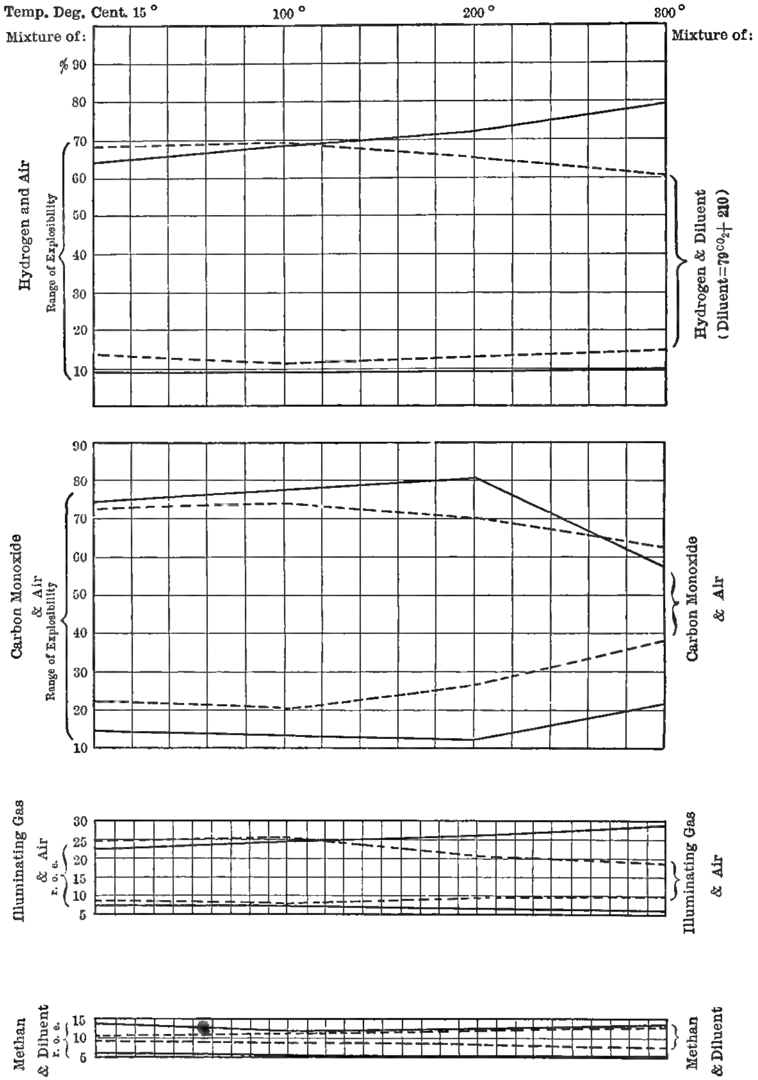


FIG. 45. — Influence of Dilution of Combustible Mixtures through Inert Gases on Range of Explosibility at Various Temperatures.

able to do this the quality of the gas used must remain invariably the same. This, however, is not always feasible, as was explained before.

Looking at the problem from the standpoint of the gas-engine designer and manufacturer, it is obvious that they would prefer to have only to deal with one dynamic medium of fixed chemical and physical properties, such as steam is. This being impossible, they are forced to demand from the concern manufacturing the producer certain guarantees as to the calorific value and other characteristics of the gas which is to be used in their engines. Carbon monoxide and hydrogen being the principal active constituents of all power gases, it is of interest to know which of the two is the more desirable to have. The temperature at which hydrogen ignites is considerably below that of carbon monoxide, and the rapidity of flame propagation at atmospheric pressure is about thirty times greater. Its diffusion properties are by far more favorable than those of carbon monoxide, so that its admixture with air is accomplished in a much shorter time; it can stand a much larger surplus of air for combustion. Its presence, therefore, determines the manner of ignition and the temperatures prevailing at various points of the inner walls. On the other hand, minor variations in the hydrogen content are of great influence on the speed of ignition or rather of flame propagation throughout the whole mixture, and therefore on engine output and consumption.

A gas to be of ideal composition for the engine builder must, therefore, not contain too much hydrogen, so as not to make the engine oversensitive to premature explosions, but enough so as to assist the slow and after-burning carbon monoxide, and to accelerate flame propagation throughout the mixture.

If an engine possesses provisions for automatically adjusting the point of ignition to the load, that is, retarding ignition at the higher loads, then an excess addition of hydrogen to the gas will serve to secure a reasonable range of overload capacity of the gas engine. It is known from producer practice that we can increase the calorific value of the gas by feeding an excessive amount of steam or water to the air passing through the fire. Of course, this practice cannot be continued for very long, else the fire will grow dead and no heat will be left available for decomposing the steam. Thus peak loads of short duration may be compensated for by increasing the intrinsic heat value or quality of the dynamic medium in the gas engine, since its quantity is rigidly fixed by the cylinder suction capacity, with engines as at present constructed.

For large power plants running on blast-furnace gas it is advisable to provide for some storage or reserve capacity of a richer (natural or coke-oven) gas, which may be admixed with the lean gas in quantities determined by the governor or by the attendant, according to the degree of overload.

Under "Thermal Considerations" (see page 61) were discussed some of the principal conditions which govern the combustion efficiency of gaseous fuels in modern heat engines, and the conclusion was reached that a pure mixture of equal composition throughout the mass and quickest combustion or heat influx at an early part of the stroke form the fundamental requirements for cyclic economy. The constructive means offered for the solution of the problem were found to be highest possible compression of a lean mixture, suitable form of clearance space, and proper position of the sparker. A few words may here be added on the latter point.

Location of Igniters. — With a regular and symmetrical form of the combustion space of cylindrical or annular form it is obvious that (provided the mixture be in accordance with theoretical requirements, namely, pure and of equal composition at all points) the center of the space is the ideal place for the igniter, provided the radial distance which the flame has to travel is not abnormally long. In small and medium-size single-acting engines it is usually quite possible to place the igniter in the ideal center position, and the great efficiency of the Güldner engine already referred to is to a considerable extent due to that arrangement. In large double-acting engines conditions are different. The distance which the flame has to travel becomes so large that several igniters are necessary and the question arises anew where to place them. It is well-nigh impossible to reach the center of the space or its neighborhood, as the cylinder cover must be free from apparatus and connections which would have to be disconnected when removing the piston or inspecting the valves. It is therefore necessary to let the igniter plugs enter the combustion chamber through lugs connecting the inner and outer cylinder walls at some convenient points of the circumference. One point naturally suggests itself as immediately below the inlet valve, provided the latter be mounted on top of the cylinder, as it is believed and also quite probable that the purest mixture will be somewhere near the passage through

which the incoming fresh charge must pass, and which it must positively scavenge of the residual burnt gases of the preceding power charge.

The second igniter is in almost all modern engines placed directly opposite the first and immediately above the exhaust valve or pocket. Though this arrangement facilitates the construction of the igniter gear which can thus be built symmetric for both sparkers, it is by no means the best place that could be chosen. All outgoing burnt gases which are expelled by the returning piston have to pass the passage or pocket above the exhaust valve, and it is absolutely certain that after the completion of the exhaust stroke in four-cycle engines the whole clearance space is filled with residual burnt gases of nearly atmospheric pressure. It is impossible to figure with certainty on the scavenging action of the outflowing exhaust gases, since their movements depend entirely on local conditions of installation. During the following suction stroke the incoming new charge only passes through the upper part of the combustion chamber, leaving the residual gases practically undisturbed in the neighborhood of the exhaust valve. These residual gases are subjected to the suction effect of the piston, but this is of no consequence with mechanically operated and properly opened inlet valves of correct proportions. They are further subjected to the influence of the water-cooled cylinder walls, which influence causes them to reduce their volume, such shrinkage having quite a noticeable and favorable influence on the efficiency of the suction stroke. During the following period of compression all fresh and residual gases are pressed into the clearance space, but the time for diffusion being so very small, it is not likely that a marked displacement of the burnt gases from the neighborhood of the exhaust valve will occur. Consequently the second igniter must always work in a diluted atmosphere consisting, for the greater part, of nitrogen and carbon dioxide, which, if the upper igniter fails to act, offers almost no chance for a reserve ignition, for which the second igniter is primarily intended. The other purpose, that of reducing the space which the flame has to propagate, remains unaccomplished with the failure of the first. So it is a logical demand to place the second igniter away from the exhaust valve and at some point midway between the latter and the inlet valve, which is reached by the

incoming fresh charge and offers some chances that ignition is actually obtained, even if the upper igniter should fail to act. At the place where most manufacturers put the second igniter in their present types of engines it is of merely ornamental effect.

In commenting on the problems of ignition Mr. Reinhardt maintains that, since water cooling of the igniter barrel has been found to be unnecessary, the plugs can now be easily removed without disturbing the water connections. To quote:

"The rapid removal of plugs is important, because the presence of bad gas and the non-production of the spark are the principal causes, in modern engines, of a refusal to start; happily this does not often occur. If the magneto-electric apparatus is in good order, and yet ignition does not occur, it clearly indicates that the plug is covered with moisture, and hence no spark can be originated.

"Dampness can be deposited during the night when the engine is not running, also when the admission and exhaust valves are open. In starting it may be condensed and settle from the compressed air used, if this contains moisture. In many plants the rule is to remove the plugs each time the engines are started and thoroughly heat them.

"To prevent water or moist compressed air being carried over from the air holder, care must be taken to drain the latter, also to take the air from the highest point of the holder.

"Should ignition fail at one end of the cylinder while the engine is working, this requires the driver's special attention. This failure may be occasioned by a leakage of the cooling water from the piston, at a pressure of 3 to 5 atmospheres, by the partial fracture of the piston, of the walls of the cylinder or of the cover. This water, leaking out during the suction period, squirts against the plugs on the return stroke of the piston."

Effect of Size of Combustion Space, Engine Speed, Time of Ignition and Mixing. — Coming back to our original discussion of modern views on internal combustion, it remains to discuss the fundamental relations between inflammability of the charge, size of combustion space and speed of the engine. Güldner, in his excellent work on the "Design and Construction of Internal Combustion Engines," treats of this question for the first time on the basis of a mathematical analysis which is interesting and of importance. The following is a short résumé of the original German treatise. "Assuming the rate of flame propagation

to have a certain value v, the distance traveled by the flame and corresponding to the greatest extension of the compression space to have a value l, and representing the number of revolutions per minute by n, the maximum pressure of explosion which occurs when inflammation is ended is indicated by the point a in the diagram Fig. 46, we have during the time of inflammation, $t = \frac{l}{v}$ seconds, the travel of the crank represented by the crank angle $\beta = t\, n \frac{360}{60} = n \frac{360}{60} \frac{l}{v}$ deg.; and assuming infinite piston-rod length, the corresponding position of the piston is found to be

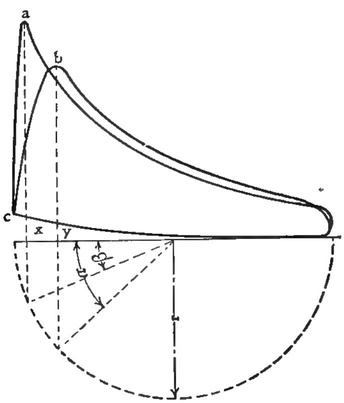


FIG. 46. — Diagram Showing Effect of Piston Speed on Inflammation and Capacity.

$x = r\,(1 - cos.\, \beta)$. Leaving other conditions unchanged, but doubling the number of revolutions per minute, the travel of the crank covered during the time while inflammation is perfected, and the piston travel x, increase respectively to $\alpha = 2\, n \frac{360}{60} \frac{l}{v}$ deg. and $y = r\,(1 - cos.\, \alpha)$, and the explosion pressure does not reach its maximum value until at the point b. Together with the number of revolutions, therefore, the angle of inflammation has also been doubled. The area $a\, b\, c\, a$ represents the loss of work produced by the unallowable crank speed.

"The second equation indicates the two ways which are available for getting around this loss, namely, either by increasing the rapidity of flame propagation v, or by reducing the distance l which the flame has to travel. The compression of the charge

is advantageous toward both sides in so far as it decreases the clearance volume and thereby *l*, as well as improves on the ignitability of the mixture and therefore on *v*. Consequently the higher we compress the faster the engine can run from the standpoint of, or in compliance with, the technical requirements for perfect combustion, and the weaker may be the mixture employed.

"Another means already referred to, to bring the maximum pressure of combustion nearer to the dead center, and one which is chiefly used with gases of low calorific value and is also employed in some automobiles and large engines working on richer mixtures, is advancing the time of ignition of the charge. If a gaseous mixture of inferior ignitability requires for its perfect inflamma-

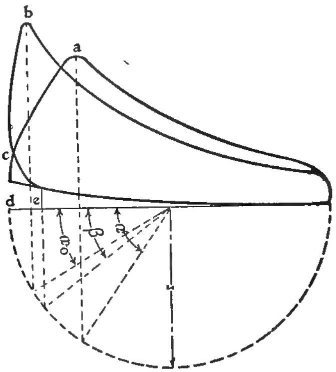


FIG. 47. — Diagram Showing Effect of Firing on Inflammation and Capacity.

tion a time interval corresponding to the crank angle α in Fig. 47, then the explosion pressure obviously occurs at the point *a* of the diagram. If, instead of at the inner dead center, ignition is produced before the end of the compression stroke, for example, at a position of the crank represented by the angle β, then the inflammation of the charge progressing at invariable speed is ended after a forward crank travel indicated by α, and therefore the maximum pressure exercised on the piston is shifted from point *a* to *b*, that is, nearer to the dead center. By thus advancing the time of ignition an amount of work is gained corresponding to the difference between the diagrammatic areas *a b c a* and *c d e c*, minus the strip of area over the curve *b*, leaving out of account the immediate consequences of premature ignition. This

gain would not be annulled before equality of the diagrammatic areas is established, if practical reasons (knocking of the gear, etc.) did not force one to stop at an even earlier period. In any case, this rough investigation shows that the correct timing of ignition depends on the composition of the charge as well as on the size and form of the combustion chamber and on the speed of the crank rotation.

"Now it is not only the comparatively low speed of flame propagation which prevents the number of revolutions of an engine from exceeding certain limits, but the mixing or diffusion of the molecular particles of the charge also forms an obstacle that is quite as difficult to surmount. The diffusion of gas in air requires a certain time, which with combustible mixtures is by no means so considerable as is usually assumed. The well-known coefficients of diffusion afford only a doubtful basis of comparison in dealing with this important question, as they invariably have reference only to such gases and such temperature and pressure conditions as are never obtained in the cylinder of an internal-combustion motor. Yet these results of laboratory investigations show that also for the gas-engine builder the time of diffusion is no negligible quantity, and emphasize the necessity that he must take good care not to make this time less than the duration of at least one piston stroke, as is sometimes done, for example, by wrong methods of regulation. According to recent tests made by Petreano, 1 liter of methane requires about 6 seconds for complete diffusion in 1 liter of air, and from 10 to 12 seconds if it is forced into about 5 liters of air. But the theoretical quantity of air required for perfect combustion of methane is double the proportion stated. Though the warming up of the mixture during the suction and compression strokes acts favorably on the diffusion of the gases, this advantageous influence is neutralized by the increase of the density of the charge. The mobility of the gas molecules, that is, their freedom of motion, is less pronounced the greater their density.

"For two gases of equal molecular weight and equal inner friction the rate of diffusion is generally expressed by the equation $D = \frac{\eta}{\delta}$. This, in a different form, is also stated in the equation of Claudius for what he terms the "medium distance": $L = \frac{a^3}{\frac{4}{3}\,\pi\,s^2}$, wherein a represents the original space between the molecular

centers (which is a function of δ), and s is the distance between the centers of two molecules when striking each other. In any case it is certain that even with engines running at slow speed (150 to 180 r.p.m.), the time duration of two piston strokes is hardly sufficient for real and perfect diffusion of the gases, and that such diffusion is extended into the expansion stroke. After-burning is alone hereby accounted for. In high-speed engines the imperfectness of mixing must necessarily be even more pronounced, a fact which is also borne out by practical experience.

"Such considerations as the foregoing suggest the advisability of forming the mixture not in the working cylinder proper, but in a sufficiently large mixing chamber, independent of the movement of the piston, and allowing the engine to draw the ready charge from this space according to the requirements. With oil motors this method has found occasional application (as for instance in the Priestman motor), while with gas engines it has hitherto hardly ever been used, because, primarily, of the complexity and the danger of explosion involved."

That the separate formation of the mixture outside the cylinder can actually have a favorable influence on the combustion process is proved by some experiments of Petreano's made with his mixing apparatus, Fig. 48, on a Deutz slide-valve motor. Air and fuel enter into the space *a* from above. The fuel (oil) is drawn in by metallic wicks *b*, which surround the center tube, and is taken up by the air passing by. The ready mixture enters into the motor through a mixing chamber *C*. Mixing is facilitated by heat from the exhaust gases, which are passed through the central tube of the apparatus. Indicator cards taken while the mixer was inserted all show a much quicker rising inflammation line and a larger area than without premixing. Perfect combustion at the inner dead-center position of the piston and with the smallest radiating surface also effects a decrease in the consumption of cooling water, as the delivery of heat to the latter is diminished during the expansion stroke. To prove this Petreano made his experiments also without renewing the cooling water contained in the jacket, employing what is called evaporation cooling. The quantity of water thus evaporated and which had to be supplied was found to be 1.2 liters after a 10-hour run which was interrupted three times (distributed over 3 days), using alcohol of 90 per cent., and 2.5 liters after 4 hours of unin-

terrupted running with gasolene. After $2\frac{3}{4}$ hours' working with alcohol of 70 per cent. the cooling water was not heated over 80 deg. C. The cards taken were invariably good from beginning to end. The report does not give any information on the engine output and other items. It would seem, however, that the formation of the mixture in a special vessel outside the cylinder will become of practical importance, especially if the speed of rotation of

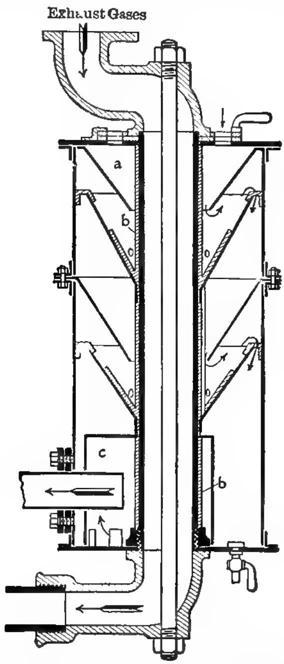


FIG. 48. — Petreano's Apparatus for Premixing the Charge.

the gas engine should continue on the increase, as it has been hitherto.

If diffusion cannot be assisted by a prolongation of the time of mixing, it remains to accelerate it by artificial means, such as a liberal air supply and the thorough distribution of the combustible gas in the air. The first expedient being very limited, the second deserves the most careful attention of the designer. The constructive means available for the mechanical distribution of the charge particles ordinarily consists in increasing the diffu-

sion area by finely dividing the two constituents of the charge. This question will be treated in detail in the discussion of the respective constructions. The effective disturbance or whirling around of the mixture by means of changes of direction of the flow and variations in cross section of the passages, the bouncing of the particles of the charge against each other by injecting a forceful stream of gas or air into the mixing chamber, and other kindred means, deserve a far more extensive adoption than has been hitherto practised.

In the Diesel motor the mixture is agitated even during inflammation and combustion by injecting a finely atomized spray of compressed air under a pressure of from 6 to 10 atmospheres and assisting the distribution of the air by special forms of inlet nozzle, etc. In exploding engines where the mixture must be diffused at the point of ignition, the charge is artificially set in whirling motion only during the suction stroke, and during the compression stroke just so far as compression of the charge naturally causes it. An exception is found in some two-cycle engines, in which the gas is pressed into the air during the compression of the latter. The fact that, notwithstanding the short time available for diffusion in these engines, the charge is not worse but better mixed than in older four-cycle engines confirms the theory as to the favorable effect of agitation on the mixing of the constituents.

Starting Large Engines

To get a modern large steam engine, working with high pressure and superheat, warmed up ready to start takes several hours. In addition there is a considerable time required between starting and carrying full load. With large gas engines the whole process lasts only a few minutes altogether.

Among the various methods of starting gas engines the one using compressed air has met with most widespread adoption. The principle is simply to convert one or more cylinder of a two-cylinder or multi-cylinder engine into a compressed-air motor by throwing out of service the main admission cams and throwing in two auxiliary cams which engage the exhaust valves in a double-throw instead of a single-throw movement. Compressed air is then admitted to the valve chamber at 150 to 250 lb. pressure, according to the size of the engine cylinder and to the kind of

service rendered. After one or two strokes by compressed air the regular combustion process begins in the other cylinder or cylinders; the supply of air is then cut off and the cam mechanism returned to its normal position. The time required to bring the engine from standstill, cold, up to full speed is about 25 seconds, if the igniting mechanism is automatically retarded. One minute is sufficient to start an engine of, say, 500 h.p. up to full load.

Large engines are provided with an auxiliary motor and reduction gear acting on the fly-wheel, for the purpose of setting the moving parts in such position as to allow inspection of the cylinder interior for cleaning and repairs, also for the purpose of getting ready for starting.

The Nürnberg Company furnishes with its engines complete sets for starting with compressed air, all valves and levers being so located and arranged that one attendant can readily start the engine without changing his position. Fig. 49 shows the balanced air-starting valve and its actuating mechanism as built by the Nürnberg engineers. Fig. 50 shows the complete starting mechanism as employed in European practice (Deutz construction). In this diagram *A* is the valve controlling the flow of air from a separately driven air compressor to the tank, and *B* a similar valve in the pipe connecting the tank to the engine. Both valves are mounted on one pillar, which also has screwed on top of it a gage indicating continuously the pressure in the tank. Regulation of the supply of compressor air to the engine cylinder is effected by means of an automatic spring-loaded inlet poppet valve, the stem and disk of which may be released or held fast by screwing down or unscrewing the hand wheel *C* at the engine end of the air pipe. A plug valve *D* is inserted in the air pipe immediately ahead of the inlet valve. Before starting the engine, the fly-wheel is turned into such a position that the crank stands about 30 deg. above the inner dead center. The starting gear is adjusted so as to open both the inlet and the exhaust valves at the proper moments, the action being such as to allow part of the compressed air to escape during a fraction of the return travel of the piston and thereby reduce the compression pressure to about 28 lb. per square inch for rich gases, and about 56 lb. per square inch for poor gases. In the meantime, the electric ignition device has been automatically

adjusted so as to retard ignition for the first few strokes. The main fuel or gas valves must, of course, also be set so as to produce the most favorable mixture for starting conditions.

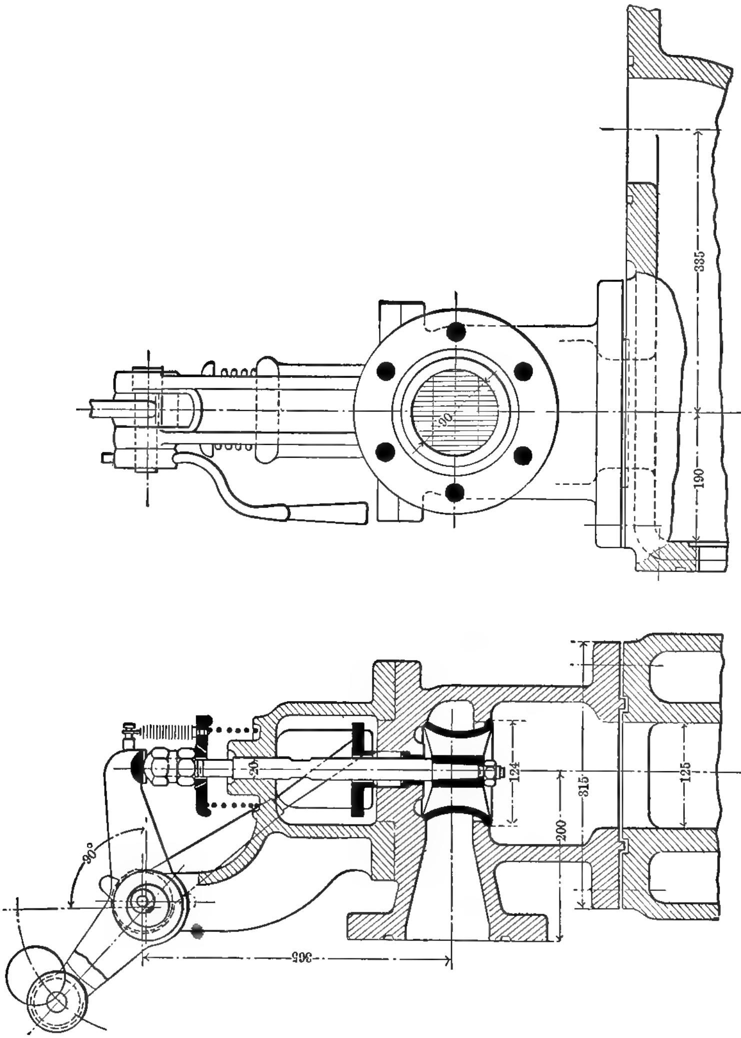


FIG. 49. — Balanced Air Starting Valve (Nürnberg).

To start the engine, the air-stop valve *B* is opened, the automatic inlet valve released by screwing down the hand wheel *C* to the full extent, and compressed air is then admitted by turning

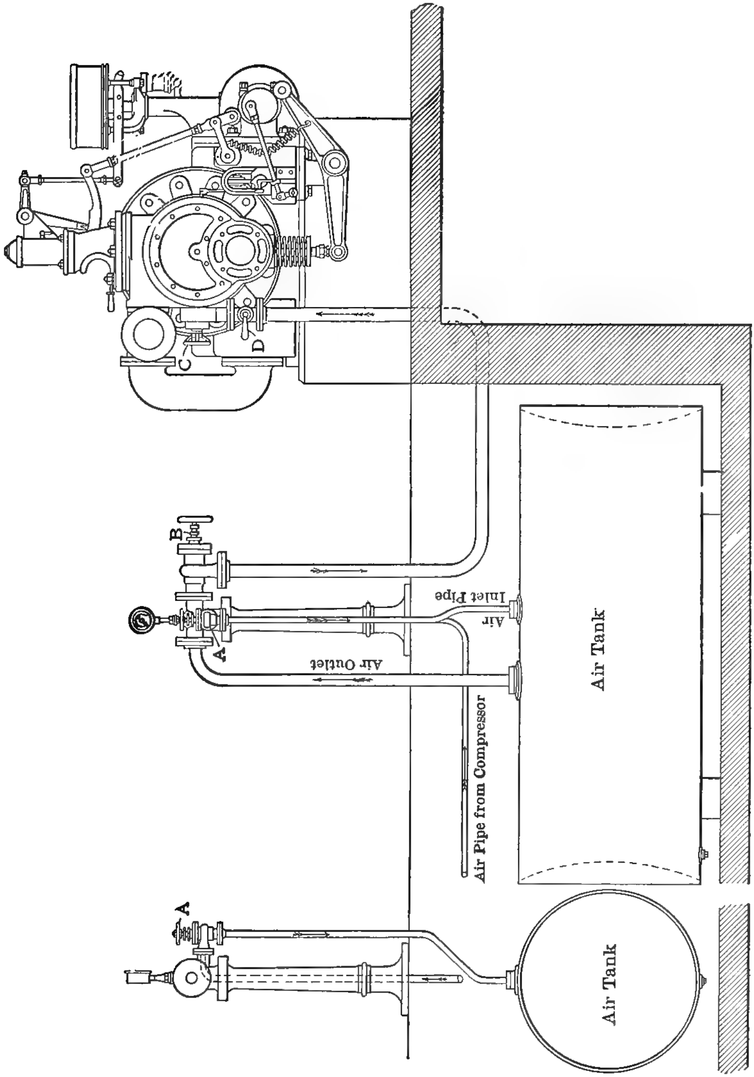


FIG. 50. — Compressed-Air Starting Equipment (Deutz).

the handle D 90 deg. The piston will then begin to travel slowly on its outward stroke, and just before it reaches the outer dead center the handle D must be returned to its original position, shutting off the air supply. The first impulse given to the flywheel by compressed air will usually be sufficient to produce

several revolutions at a speed of about one-fifth of the normal, when no load is on. During the following (suction) stroke a mixture of gas and air in the correct proportions is taken in, and on the next stroke compressed and ignited. If the right mixture does not happen to be obtained and ignition fails to occur, another compressed-air impulse is given, which will always produce the desired result. After the first power stroke has been obtained the air-supply valve *B* is closed and the automatic inlet valve held fast by unscrewing the hand wheel *C* until its hub bears against a collar on the valve stem. Thereby the valve disk is firmly pressed on its seat. Then the starting gear is pushed back into the running position, so as to allow the mechanism to open the valves at the regular intervals only. The point of ignition is thereby automatically advanced and may now be adjusted by hand or by the governor of the engine so as to suit the changed conditions. When the main gas-admission valve is set in the correct running position, all operations for starting have been duly executed. It may be added that it takes less time to perform the complete cycle of operations than it takes to describe it.

The starting pillar with its gage and valves must be located on that side of the engine where the starting valve gear is located, and all the controlling apparatus, such as the speed counter, main gas- and air-admission valves, ignition timing gear and, if possible, the more important visible overflows for the cooling water, must be combined on this side and within convenient reach of the operator.

It is not advisable to let the air pressure in the tank exceed 170 lb. per square inch. It is also of advantage to shift the roller, or whatever device may serve for relieving compression at starting, into the starting position immediately after shutting down the engine and while the fly-wheel is still in motion, as it is difficult to move the gear when the engine is at rest, or when the crank happens to be in an unfavorable position.

From the foregoing it will be understood why, with this method, the double-acting two-cycle engines require the lowest air pressure to start with, and that they can start even with a load on. K. Reinhardt gives the following data from recent German practice:

"The pressure of the air employed ranges from 6 to 25 atmos-

pheres. In most cases the valves work in the same cycle when starting as when running. The compressed air is admitted at what would usually be the commencement of the combustion stroke and gives the engine a start. The moment of admission of the compressed air should be determined in consideration of the fact that, in case of an ignition of the gases now drawn in, the combustion pressure attained is higher than that of the compressed air. Further, no such admission should take place before or during combustion, as it would deteriorate the mixture. In multiple-cylinder engines, particularly two-cycle engines, which can start with a corresponding small load, starting is often possible by admitting compressed air to one cylinder. In such cases ignition must be allowed to take place in the second cylinder, then the compressed air must be shut off in the first cylinder, and then, after a few revolutions, and after the moisture originating from the compressed air has been evaporated by the heat developed by compression, the gas valve in the first cylinder must also be opened. In starting gas engines the ignition mechanism must be so arranged that ignition of the mixture takes place at a time which corresponds to a smaller crank angle, distant from the dead center, than obtains at the regular speed. In the same manner the ignition must also be regulated by hand if the number of revolutions of the engine is variable, as is the case with gas blowers."

The use of a mixture of gas and air for starting has now been altogether abandoned, the storage of an explosive mixture under pressure in a tank being a rather dangerous practice. However, when independent air and fuel pumps are used with two-cycle engines, they may be started by an electric motor serving to drive them, and may deliver the two constituents of the charge separately into the engine, there to mix and ignite. This, of course, obviates all danger.

A still better method and one which is recommended for general adoption, if there be a source of electric energy available, as in the case of large power plants, is to use an auxiliary motor to start the engine directly by turning its fly-wheel through a reduction gear and automatic clutch. The writer believes that starting with compressed air is an indirect way which can eventually be overcome. It requires, besides the auxiliary motor, an air compressor, an air tank (or, better, two, one

serving as a reserve), pipes connecting the compressor to the tank or tanks and the latter to the engine, check valves, pressure gages, arrangements for shifting auxiliary cams, and starting valves entering the combustion chamber; all of this equipment being used only one or two minutes in a day of actual running. This can be eliminated by using the auxiliary motor geared directly to the fly-wheel, while in the case of two-cycle engines the auxiliary motor may be fully utilized for driving the pumps. Moreover, the adjustment of the inlet to starting conditions is no longer necessary, as air and gas are at once drawn in in the right proportions. Some large firms on the continent have readopted this practice, which was in use long before starting with compressed air became fashionable.

The arrangement provides for a small electric motor driving through a gear meshing with teeth on the fly-wheel of the gas engine. As was said, the one precaution that must be taken is to provide means for throwing the motor pinion out of mesh as soon as the fly-wheel has attained its normal speed. Another difficulty is to get the speed which is necessary in order to obtain ignition.

The latest device of this type is built by the Felten-Guilleaume-Lahmeyer Works in Germany. The motor is thrown in mesh with the fly-wheel and started up by a single turn of the starting wheel, and the gears are thrown out of mesh automatically when the fly-wheel has attained its speed. The accompanying sketch, Fig. 51, gives a schematic view of the arrangement. The electric motor *m* drives the disk *a* by means of a chain. Pivoted on the disk is the toothed gear wheel *b*, which meshes with another wheel *c*, supported by the swing lever *d* in such a way that it can travel around the center of *c*. The lever *d* is connected by means of a strong spring *f* with a toothed segment *g*, which may be shifted by means of the toothed wheel *j* and lever *h*, and which, when moving in the direction indicated by the arrow, catches the lever *d* and also the toothed wheel *c*, turning it until the latter meshes with the large toothed gear *w* of the fly-wheel. Through the electric starter *r* and lever *h* the current for the electric motor is switched on at the same time. By turning lever *d*, and thereby the toothed segment, still farther in the direction indicated, the spiral spring *f* is more stretched, while the starting resistance is short-circuited in a similar measure. When arriving at its end

position, the segment is locked by means of the latch *k*. As soon as the fly-wheel attains a higher speed than can be imparted to it by the motor, then the toothed wheel *c*, and therefore the lever *d*, are shifted in the direction of the fly-wheel travel, thereby unlocking the spring device as shown in the sketch; the toothed segment, accelerated by the spring, moves backward and switches

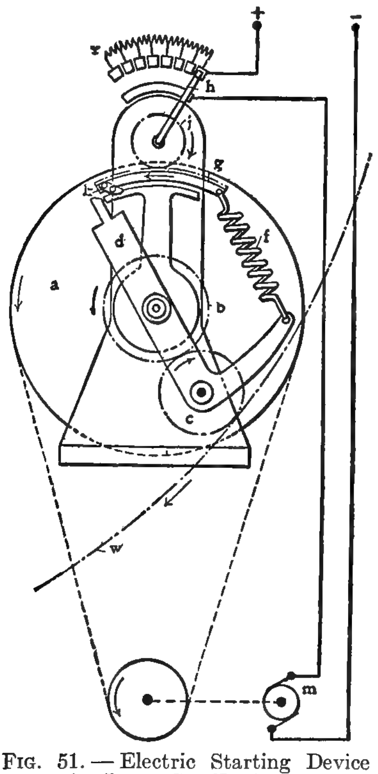


FIG. 51. — Electric Starting Device for Large Gas Engines.

off the current by means of *h*, thus bringing the motor to rest. The lever *h* and toothed wheel *c* are simply pushed aside by the fly-wheel and thrown out of mesh with the gear *u*.

The attendant has therefore only to turn gradually the hand wheel on the starting shaft until the lock on the toothed segment comes into operation. While the starting device continues its operation automatically the attendant can go to

the main admission valve and open it. This is all that is required.

The above arrangement is built up to tooth pressures of 3000 kg. and several continental gas-power plants are thus equipped. For higher pressures an arrangement is preferred in which the motor drives the fixed-tooth wheel by means of a worm gear. In many cases it is desirable to control the operation of starting from a central place, such as the position where the valves of the gas engine are located, in order that starting and admission of the working medium may be regulated at the same time. For this purpose the starting device is equipped with distant control and

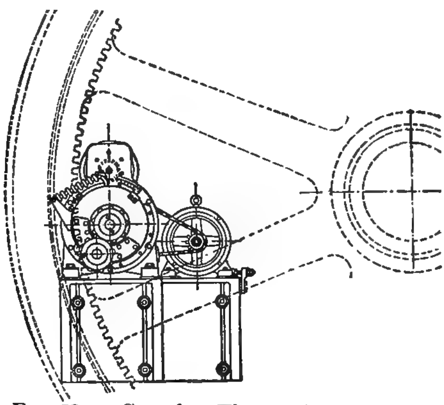


Fig. 52. — Complete Electric Outfit for Starting Gas Engines.

is actuated by means of a mechanical or electrical relay. Both types of starting motors are shown in Fig. 52 and Fig. 53 respectively.

Another Method of Starting Electrically

When the gas engine is coupled directly to an electric generator and a battery is available, which is usually the case in large central stations, the motor of the booster set may be started up directly from the battery. The dynamo is also excited from the same source. The generating part of the booster is connected with the dynamo through a double pole switch. The booster is started and the switch is closed. Now the booster begins to deliver current and the dynamo runs as motor, its speed being regulated by varying the amount of excitation.

This mode of operation has been introduced with success in smaller plants, and it was found that the consumption of electric energy was only one-third of what was used when driving the dynamo through a starting resistance from the battery, as a motor.

Pumps

Pumps used for circulating the cooling water or, in two-cycle engines, for the delivery of air and gas, must not be driven from the valve-actuating shaft. They are mostly driven from the main shaft by special gears or other connections, or when placed underneath the engine to reduce the floor space, from

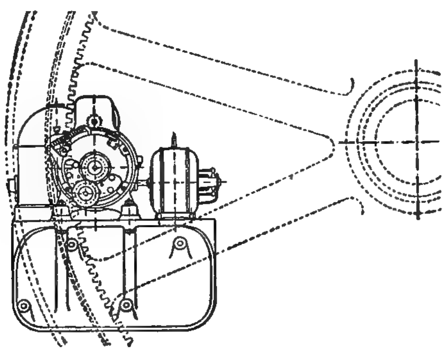


Fig. 53. — Electric Starting Outfit for Gas Engines up to Largest Size.

some of the reciprocating parts of the engine. It is, however, becoming more and more customary to operate pumps of all kinds by separate motors independent of the engine, as in the case of the air and circulating pumps of condensing steam engines. The writer advocates a plan whereby the output of all the various pumps is automatically adjusted to the load. For large engines it is desirable to make provision to this end, as it is obviously wasteful to pump the same quantity of cooling water and lubricating oil into the engine whether it is running at full load or at no load. Similarly, it is better in two-cycle engines to regulate the output of the gas- and air-delivery pumps by controlling their speed from the governor of the main engine, provided they are driven by separate motors, than to run them at the same speed under all loads and throttle their intake or over-

flow. Regulation can be made perfect by adding a governor mechanism acting directly on the inlet valve of the engine.

Lubrication

With pistons supported by external guides, and with correct cooling, the lubrication of cylinders is no longer a difficult problem and can be made so perfect as to reduce greatly the wear and the depreciation of the engine against what was obtained in the pioneer days of the gas-engine industry. Reciprocating sight-feed oil pumps operated from the cam shaft force oil in proper quantities to the cylinders, stuffing boxes, exhaust-valve steam guides and governor steps, while drip cups may be used for the various other parts.

In the Nürnberg engines all external parts receive their supply of oil from a large elevated tank, by a circulation or continuous return system, the lubricant flowing through large tubes — avoiding accumulation of dirt and allowing easy regulation — to the basement of the engine room, whence it is raised back to the tanks by a pump driven from the engine, after having undergone a process of filtration. The main bearings of the crank-shaft must be lubricated by continuous oil feed under pressure, which is the only way to secure reliable running of large revolving surfaces subjected to heavy loads. For all external parts an ordinary lubricant may be used, while the internal parts, which are exposed to high temperatures, require an oil of high flash-point.

It is often maintained that excessive lubrication is the cause of back-firing, and special draining devices have been fitted on some engines to allow the surplus oil to be blown off while the engine is working. In modern engines all foreign matter is expelled through the exhaust valve on the return stroke of the piston. To facilitate this, the valve seat is located slightly below the bottom level of the cylinder. With double-acting engines liberal lubrication is the safest practice. Space limitations do not allow treatment of this subject as extensively as it deserves. Readers are therefore referred to special treatises dealing with this problem, among which may be mentioned a paper on "Bearings" presented at the meeting of the American Society of Mechanical Engineers, at New York, December, 1905; this contains much valuable information on lubrication.

Test on 1200-h.p. Nürnberg Engine

All details of large gas engines as built by the Nürnberg factory, so far as they offer something new over the design of large steam engines, have now been dealt with, excepting such mechanisms as igniters, oil pumps, governors, etc., the design of which is better not undertaken by builders of large gas engines; they may be bought to advantage from firms which make a special business of manufacturing such apparatus. Complete drawings of the Nürnberg and other engines will be found on the special tables at the end of this book.

A Test with Blast-furnace Gas

Capacity in Kw.	Rev. Per Min.	Duration of Test.	Number of Trial.	Average Pressure for both Cylinders	Output of both Cylinders in i. h. p.	Gas Consumption Per Hour.		Heat Value of Gas Per Cu. Ft.	Heat Units Per Hour.		Current Strength in Amperes	E.M.F. in Volts.	Load in Brake Horse-power	Efficiency of Dynamo: %.	Efficiency of Gas Engine: %.
						In Cubic Feet	In Cu. Feet Per i.h.p.		Per i. h. p.	Per Brake Horse-power					
158.3	106	33′	I	. . .	. . . .	58,693	101.0	88.48	8984	18,532	674.2	234.9	280	77.5	48.5
357.1	105.8	28′	III	42.5	807	81,188	100.6	88.48	8452	12,262	1522.6	234.5	557	87.5	69
583.7	106.3	29′	IV	60.0	1146	105,167	91.5	89.38	8214	10,794	2467.8	236.56	871.5	91	76.2
698	106.5	26′50″	VI	68.7	1312	113,654	86.9	89.60	7829	9,921	2956.1	236.46	1037	91.5	79
755.3	106.1	25′51″	VIII	71.4	1359	118,551	87.2	90.72	7937	9,675	3213.8	235	1115	92	82.1
776	105.8	25′51″	IX	73.1	1388	118,551	85.5	88.93	7619	9,226	3291.5	236.07	1147	92	82.6
803	105.6	25′20″	V	75.3	1427	120,705	84.6	87.92	7460	8,976	3417.5	234.87	1186	92	83.1

In the accompanying table are given the results of a test made by Professor Riedler, of Charlottenberg, on a 1200-h.p. Nürnberg double-acting tandem engine having cylinders 850 mm. (33.46 in.) in diameter and a stroke of 1100 mm. (43.3 in.); the speed was 106 r.p.m. and the fuel blast-furnace gas of a calorific value of 31,750 heat units per cubic meter (89.90 per cubic foot). The test was made in September of last year, in the Rombach Iron Works, Alsace-Lorraine, Germany, after the engine had been running under variable loads for five weeks without a stop. The results are therefore not the best which it is possible to attain when working under more favorable (shop test) conditions, but they show a performance that can be absolutely relied upon in actual practice.

There are in the Rombach works altogether 72,300 h.p. generated from blast-furnace gas. The plant contains four engines

of 900 h.p. running at 80 r.p.m., each driving a blowing engine delivering 800 cu. m. of air per minute at a pressure of 0.5 atmosphere; one engine of 2700 h.p. running at 45 to 90 r.p.m., and driving a blowing engine delivering 700 cu. m. of air per minute at a pressure of from 2 to 2.5 atmospheres for the steel-smelting plant; five gas engines of 1200 h.p. running at 107 r.p.m., and driving electric generators, two being direct-coupled to direct-current dynamos furnishing current at 220 volts for light and power purposes, while three are coupled to three-phase alternating-current generators. As is evident from the table, the average thermal economy remains between 7540 and 7973 heat units per

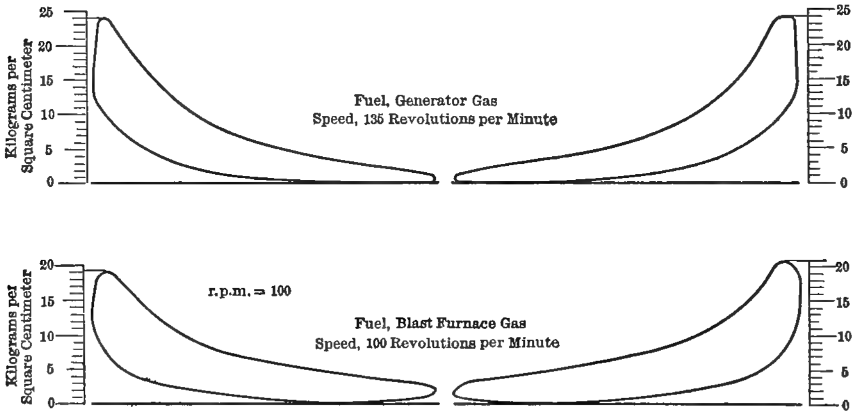


FIG. 54. — Indicator Cards from Nürnberg Double-Acting Gas Engine.

hour per indicated horse-power, while the mechanical efficiency runs up to 83 per cent.; in some trials not given here it was as high as 92 per cent. Another test was recently made on three blast-furnace gas engines, one of 1800 h.p. driving an electric generator and two blowing engines of 1000 h.p. each, running in the iron-smelting plant of the "Schalker Gruben und Hütten Verein." The heat consumption at full load remained between 7539 and 7257 B.t.u. per indicated horse-power per hour. Fig. 54 shows diagrams taken from Nürnberg engines when working on generator and blast-furnace gas, respectively.

In America the large gas-engine industry has reached a critical phase in its existence owing to the many failures which have occurred, though only the minority of cases — for obvious reasons — are brought to the knowledge of the interested public. This

is an unfortunate state of affairs. It is better to eliminate old-fashioned types and bad constructions by public criticism than to go on advocating them for selfish reasons and placing them on the market, only to undermine or forfeit the confidence of the purchaser.

The diversity of types which have so abundantly been evolved in a period of experimental and inventive speculation in this country make it impossible to speak, even now, of a condition of stability and of standardization of forms in this particular industry. If we inquire for the reason thereof the most natural explanation presents itself in the abundance of natural resources for the generation of power, which has caused the American engineer to neglect somewhat the study of more economic methods in this field. The conservatism which reveals itself to the student of power-gas engines in the employment, by the average inventor and designer, of methods and forms which have absolutely proved unfit for satisfactory service in the long run abroad may be advanced as another argument for the reason of the backward condition of the American gas engine. On the continent the large gas-engine industry has succeeded, after some years of experimenting, in reaching a wholesome commercial state which, with the proper employment of legitimate and scientific means, can also be attained in this country. And every indication points to the effect that we are rapidly approaching that desirable end.

V

THE BORSIG-OECHELHÄUSER ENGINE

The Oechelhäuser gas engine built by the Borsig works is a double-acting two-cycle machine, having a pair of pistons working in opposite directions and delivering power to three cranks of equal throw. As explained in an earlier chapter, such an arrangement gives nearly balanced forces and no couple. That there is a difference at all is due to different rod lengths, or rather to the fact that the angles of the two rods are not equal for any given crank angles, and therefore the pistons have not equal acceleration for some crank angles, even when the masses are equal.

General Construction

The effect of good balancing of the reciprocating parts is felt to advantage in the design in several parts of this engine. First, there are no horizontal forces in the frame, and, therefore, no bending moments produced. All active forces are balanced without the intervention of passive machine parts; hence the foundation bolts and bed plates of the engine can be kept comparatively light. No long beam frame is used to connect the various parts, the position of the cylinder being centered in and secured to the main frame, which contains the crank bearings and the crosshead guides; thus a good alinement is effected. All parts are connected parallel to the direction of driving forces by central flanges, and the cylinder rests freely on the base plate, allowing free expansion under the influence of varying temperatures.

In the Nürnberg engine, and as a matter of fact, almost all up-to-date engines, like the Deutz, Ehrhardt & Sehmer, Soest, Krupp, Union and others, the first cylinder is centered in and secured to the main frame, which, of course, rests on its foundation along its entire length, while a distance piece connects the

first cylinder to the second cylinder; the only part rigidly fastened to the main frame being one end of the front cylinder. All the other parts can freely slide to yield somewhat to the longitudinal variations due to the forces acting in the engine. In the Oechelhäuser engine such forces are of little importance, while their effect can be easily observed in ordinary tandem gas engines, the tail ends of which show a clearly noticeable reciprocating movement. As the foundation of such engines is considerably weakened by pits and channels, giving access to exhaust valves and room for gas, air, exhaust and water pipes, almost all of the forces are transmitted to the front foundation block, which is thus very heavily loaded and should be connected to the back part of the foundation by iron tie-rods. It is therefore bad practice to mount the engine on foundation blocks which project considerably above the level of the engine-room floor without being rigidly connected except at a great distance below the plane of reciprocating forces. Neither is better accessibility of parts secured thereby, as it is immaterial whether the inlet valves are reached by means of stairs leading up, or the exhaust valves by stairs leading down to the pit, nor is stiffness of the system guaranteed. If anything, the cost of foundation becomes greater and the appearance of the plant more monstrous and complex, and it is well not to omit entirely the ethics of appearance in the design of gas-power plants.

It is interesting to observe that the fundamental principle in the design of large gas engines in Europe, namely, that all the main parts have their proper relative positions positively and permanently fixed by male and female centering fits of large diameter, thus practically insuring self-alinement, has now been also almost universally adopted by the more prominent engine builders in this country.

Crank-shaft

A three-throw crank-shaft with two outside bearings standing far apart, as used in the Borsig-Oechelhäuser engine, is often regarded with disfavor by engineers as being heavy, difficult and costly to manufacture, while its strength is thought insufficient to meet all the varying requirements of heavy service. As the cycle of operation employed in this engine necessitates the

adoption of a crank-shaft of this kind, it becomes of the greatest importance to ascertain how far these objections are justified. Regarding strength, there is this to say: The shaft must be of such diameter that it will resist a moment of applied stresses equal to the combined maximum bending and twisting moments which are produced by forces due to the action of gas pressure plus the inertia of the reciprocating parts. In addition thereto, the shaft is subjected to bending from its own weight and some dead loads, such as fly-wheels, etc.

Using the method of calculation as proposed by Max Ensslin and employed by Professor Meyer in his analysis, which takes into account the complete set of active forces that must be resisted, the maximum stress, occurring under normal working conditions has been determined at 430 kg. per square centimeter, or 6100 lb. per square inch, and at early ignition 562 kg. per square centimeter, or 7993 lb. per square inch. The corresponding angles of deflection of the shaft are $\beta = 0.000362$ seconds and $\beta_{max} = 0.000470$ seconds.

To make these figures intelligible one must compare them with the corresponding data determined from shafts which have given satisfactory results under the severest conditions of continued practice. Using the same process of determination, we find for the shaft of a 30-h.p. Diesel engine the angle of deflection β is between 0.00024 second and 0.00118 second; for the shaft of a 100-h.p. four-cycle gas engine, it is between 0.00061 second and 0.00102 second, and for the double-throw shaft of a compound steam engine it is between 0.000279 second and 0.000412 second; all this during the critical phase of the crank travel.

Before comparing we have to combine geometrically the values of β found for any shaft with the other value β', representing the angle of deflection due to bending from its own weight, and to resolve the two loads into a resultant, by means of the parallelogram of forces. Assuming the most unfavorable case, namely, that the resultant is equal to the arithmetical sum of the two components β and β', the deflection would only be slightly larger than that of the steam-engine shaft examined, and would only be one-half and one-third of that of the oil and gas engines respectively. The angle of deflection at the place where the concentrated resultant rests in the shaft of the Oechelhäuser

engine is therefore quite within the safe limits of allowable deformation.

Another objection may be raised, namely, that the angle of torsion due to twisting of the three-throw crank-shaft may be excessive.

As the turning moment acting on the shaft occurs periodically at time intervals, there would arise the danger that synchronism between the inertia forces and shaft periods might occur and the well-known condition be established which may be termed the natural period of torsion vibration. To avoid such synchronous vibration, the shaft must be so designed that the critical period of its revolutions is kept far above the normal number of revolutions which the engine is expected to make. In the case under discussion, it is found that the critical condition is reached at 1420 r.p.m., while the shaft ordinarily turns at from 90 to 100 r.p.m. We may therefore rest assured that a crank-shaft of the Borsig-Oechelhäuser type is fully strong enough to resist the maximum turning and twisting moments, and that its deformation remains much below that in ordinary four-cycle engines.

Granted satisfaction as to the point of shaft stiffness, the remainder of the objections raised against the scheme are of little consideration. Regarding weight, it should be borne in mind that for driving blowing engines and rolling mills an engine cannot be built too heavy. The centrifugal forces set up by the crank-shafts are self-balancing.

Cycle of Operation

Before going further into an analysis of the mechanical details of the engine proper it may be well to discuss its cycle of operation, which, though often described in technical papers, has never been fully understood and appreciated, as the principles governing fluid friction in two-cycle engines were not at the time, nor are even to-day, fully mastered. The method of working of the engine is as follows: The two pistons *A* and *B*, Fig. 55, work in opposite directions and uncover near the end of their outward travel the exhaust, air and gas ports. The piston *A* first opens the longer exhaust ports and allows the products of combustion to escape until the pressure in the cylinder has fallen to the atmosphere. Then the piston *B* opens the air ports, through which scavenging air of low and decreasing pressure

enters the cylinder and sweeps out the burned gases. Immediately it opens the gas ports, allowing gas to enter the cylinder and mix with the air, which continues streaming in, whereby the explosive mixture required for a new working stroke is formed.

At the beginning of the return stroke the piston *B* first closes the gas-inlet ports and then the air ports. In order to prevent excessive admission of air through the air ports, after the gas ports have been closed, and to separate as far as possible the scavenging and charging air, there is provided an annular slide in the air chamber or receiver which is operated from the valve-gear shaft by means of an eccentric and rod and closes the ports in the receiver when the air ports in the cylinder have been uncovered by the piston. As soon as the gas ports have been un-

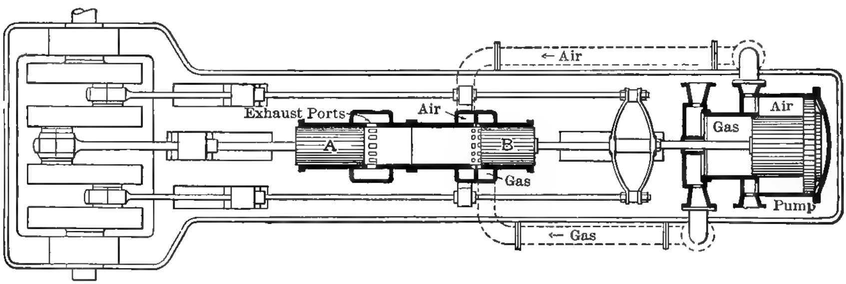


FIG. 55. — Elementary Plan of Oechelhäuser Gas Engine.

covered, the slide is opened again and air from the pump is allowed to flow in. At the beginning of the return stroke after the piston *B* has covered the gas and air ports, before the exhaust ports are closed by the piston *A*, part of the scavenging air previously introduced is swept out of the exhaust ports by the advancing mixture until the ports are completely closed. At this moment begins the compression of the charge, which is theoretically composed of two layers of scavenging and charging air inclosing a layer of mixture, the latter forming about 70 per cent. of the entire charge and representing the active stroke volume. Toward the end of compression, ignition is produced at two points of the mass of gas and air.

SCAVENGING AND CHARGING

To understand thoroughly the system of governing employed in this engine, it is necessary to examine the initial process of

scavenging and reloading. A very complete discussion of this subject was given by Professor Diederichs, of Cornell University, in the Sibley journal of May, 1904, to which readers are referred for full information. In that part of his treatise dealing with fluid friction, Professor Diederichs says: "Concerning the choice of pumps, an independent air pump with an ample air receiver furnishes the ideal conditions, for, under these conditions, we can commence or cease scavenging at will, dependent upon the setting of the valves, and if the receiver is large enough, an excess of air under fairly constant pressure is available. If the receiver be made too small, scavenging will cease too early, an excess of air not being available, and the scavenging pressure will decrease very rapidly." This statement holds true for the majority of types of two-cycle gas engines. It would, however, be erroneous to generalize the ideas expressed therein and to regard receiver capacity as one of the limiting conditions of design for all engines and, more especially, the Oechelhäuser type. There are certain types of two-cycle engines, and this is one of them, in which the whole quantity of scavenging and charging air is pumped into a common receiver provided with a common overflow valve or port.

If rich gas of high heat value is used in the engine, then the quantity of gas burned per power stroke is comparatively small, so small indeed that it may be introduced into the working cylinder together with little or no air and left to mix there with the scavenging air previously pumped into the cylinder, and yet a good explosive mixture will be effected.

In the earliest types of Oechelhäuser-Junkers engines a special gas pump was employed to introduce, according to the load, a certain quantity of gas into the working cylinder under a pressure of from 10 to 12 atmospheres. Though the time allowed for diffusion of gas injected into the air was rather short, yet the diagrams taken at that time show a very good combustion line, which proves that the mixture must have been satisfactory. It would, however, be quite a mistake to try to adopt this method in modern practice, as with the lean and voluminous power gases used to-day the quantity of gas burned per stroke is relatively very large. Besides the difficulty of compressing the large volume of gas, which constitutes one-half or more of the total volume of the power charge, in a separate pump, whereby fluid

friction and other losses are excessively increased, there is the drawback that mixing of the two constituents would only occur at the very beginning of the gas influx, while during the rest of the charging process the gas would simply sweep the air before it into the exhaust ports. Hence it becomes necessary either to have a good mixture formed in the charging pump or to introduce a certain quantity of air in the cylinder, along with the gas, and let the mixing of the two be done during the overflow.

The later types of the Oechelhäuser engines used the first of the two methods outlined, namely, a special charging pump delivering a ready mixture through the gas ports. There was, however, the danger that the gas inlet was filled with a combustible mixture, which, while entering the cylinder, was occasionally ignited and thereby the whole contents of the receiver were burned, with disastrous effects in certain parts, especially the valves of the charging pump.

If mixing is accomplished by simultaneous introduction of air and gas into the working cylinder, as is done in the latest types of Oechelhäuser engines, then there must be, besides a variation in the quantity of gas introduced, a corresponding variation in the quantity of air introduced with the gas, if close regulation and the best possible combustion are to be obtained. The simplest, cheapest, and safest way of getting at the desired result is to effect the variation of the quantity of the overflowing constituents by changing the pressure in the respective receivers. This is done most economically by changing the volumetric delivery of the respective pumps, which is best accomplished by means of by-pass valves in the respective receivers, which are opened under the influence of the governor for a longer or shorter period and in such a way that opening commences at the beginning of the compression stroke of the pump, and that a greater or smaller part of the quantity of gas and air taken in during the suction stroke is allowed to flow back into the suction pipes of the pumps at nearly atmospheric pressure.

If this method of varying the quantity of overflow by changing the receiver pressure be adopted, then it becomes at once apparent that the receiver contents must be kept as small as possible, because the actual change in quantity of delivered mixture will fall more behind the corresponding change effected by the governor, the larger the contents of the receiver.

It is possible by a simple graphic method, which was developed by Professor Wagner, to determine the mutual relation and dependence of receiver contents and range of pressure fall, provided that the quantity and average pressure of the overflow agent in the receiver be kept constant. It is found that to obtain small values for the pressure fall, the receiver volume must be made very large. Thus if we desire to work with a pressure fall of, say, 1.42 lb. per square inch, the receiver would need to have 212 cu. ft. capacity. Under such conditions, a device to adjust the quantity of overflow to the load by varying the receiver pressure would prove a complete failure. It is obvious, therefore, that there may arise conditions which allow of the adoption of small receivers without introducing into the scheme any of the difficulties pointed out in the treatise referred to. To quote: "The scavenging agent should be under low pressure; high pressure causes it to flow into the cylinder under high velocities, and besides unnecessarily increasing fluid friction, it is apt to pierce the burned gases, which is just what is to be avoided."

Borsig-Oechelhäuser gas engines have shown in actual practice highly satisfactory results with a total receiver capacity which gives for the maximum quantity of overflow a drop of pressure of 14.22 lb. per square inch. The pressure in the receiver at the beginning of the scavenging period is from 23 to 24 lb. absolute, if the engine is running at high speed. Although this pressure is rather high, yet very perfect scavenging is effected. Indeed diagrams taken under various conditions of load justify the conclusion that the combustion must be good and the reported heat consumption of 6586 B.t.u. per hour per indicated horse-power runs the thermal efficiency up to 38.6 per cent., which is an excellent result for a 500-h.p. engine working with coke-oven gas.

The reason the employment of a high-pressure scavenging agent in the Borsig-Oechelhäuser engine is not a failure is found in the favorable form of the combustion chamber and in the annular and symmetrical distribution of inlet and exhaust ports around the whole circumference of the cylinder. The air rushing into the cylinder from all sides under equal pressure first strikes the crowned piston head, which gives it a tendency to move by the shortest path toward the exhaust ports, which are likewise symmetrically distributed over the whole circumference. It will, therefore, fill the cylinder from wall to wall in the form of a

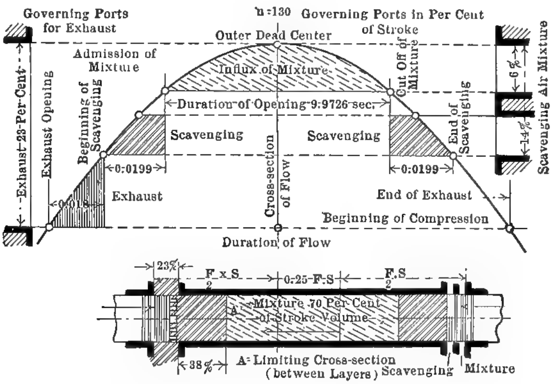
more or less compact cylindrical mass, pushing burned gas out ahead of it into the exhaust ports.

The purpose and action of the scavenging agent is often completely misunderstood. It is not that the air is desired to sweep out the cylinder throughout its entire volume in order to get rid of the burned gases and cool down the cylinder walls. Though reduction of cylinder temperature is a desirable feature with the high-compression pressures used in modern practice, it is impractical to depend on the unreliable, variable means of internal air cooling to accomplish this. The water-cooling system is a safe, reliable, and efficient method of controlling temperatures under all conditions of practice. And as to sweeping out burned gases, it has been found in practice that it is by no means necessary to expel completely the products of combustion from the working cylinder before the influx of the new power charge is allowed to begin. Evidently the fundamental purpose of the scavenging air is to prevent premature ignition of the new charge by contact with the highly heated burned gases. This is accomplished even when the scavenging air is completely mixed with the burned gases, providing that the temperature reduction of the residual products be such that the resulting temperature of the mixture of scavenging air and combustion gases is below the ignition temperature of the new charge.

It is quite likely that the most perfect mixing of scavenging air and combustion gases will occur and a higher temperature of the mixture be preserved, the smaller the quantity of air introduced. It is necessary, therefore, to use more air in the scavenging process, the more inflammable the new charge. However, there are a great many more factors to be considered, such as degree of compression, efficiency of cylinder cooling, diffusion properties, speed and load of the engine — so many, indeed, that we cannot here dwell on them in their entirety. In practice a measure for the efficiency of scavenging is found in the minimum quantity of air which it is necessary to introduce into the working cylinder in order to insure quiet and safe running of the engine. It is a different question, whether, with the introduction of that minimum quantity of scavenging air, the condition of maximum economy of running is obtained.

A few words may be said on the mutual relation between pressure fall and pump work. Let us assume that the drop of

pressure amounts to 8.5 lb. per square inch; then the pump must compress the air up to 22.7 lb. per square inch, but the discharge from the pump to the receiver begins at approximately the same moment that compression begins in the pump, because the receiver pressure has dropped to 14.2 lb. per square inch during previous opening of the ports. If, on the other hand, the drop of pressure amounts to 1.42 lb. per square inch, then the pump has only to compress the air up to 19.2 lb. per square inch. However, as the pressure in the receiver has dropped, at the previous discharge, only to 17.8 lb. per square inch, the pump has now first to compress up to this pressure



FIGS. 56, 57. — Diagram of Port Opening and Distribution of Layers (Borsig-Oechelhäuser Engine).

before the charge can be pushed over into the receiver. Upon comparing the respective diagrams taken from the charging pump, it becomes apparent that the work done by the pump in the first case cited exceeds that of the second only by a small fraction. The range of pressure fall has, therefore, only a negligible influence on the pump work. The latter is chiefly dependent on the average receiver pressure, which, however, has no direct relation to the receiver volume.

Figure 56 is a diagram of port opening and Fig. 57 shows the corresponding distribution of layers within the cylinder, under the assumption that the slide in the air chamber or receiver is not closed after the gas ports have been covered by the piston. Fig. 58 shows a combination of two diagrams taken from the air and gas receivers respectively. Ordinates t–i and t–a corre-

spond to two inner and one outer dead centers. The travel of the piston which covers and uncovers the air and gas ports in succession is represented by the curve k. The direction of the piston travel is indicated by the arrow. When time t has elapsed, the piston has traveled over a distance represented by s. The hatched rectangles show the air and gas ports, and the distances b_1, b_2, b_3 are drawn to the same scale as the piston stroke h.

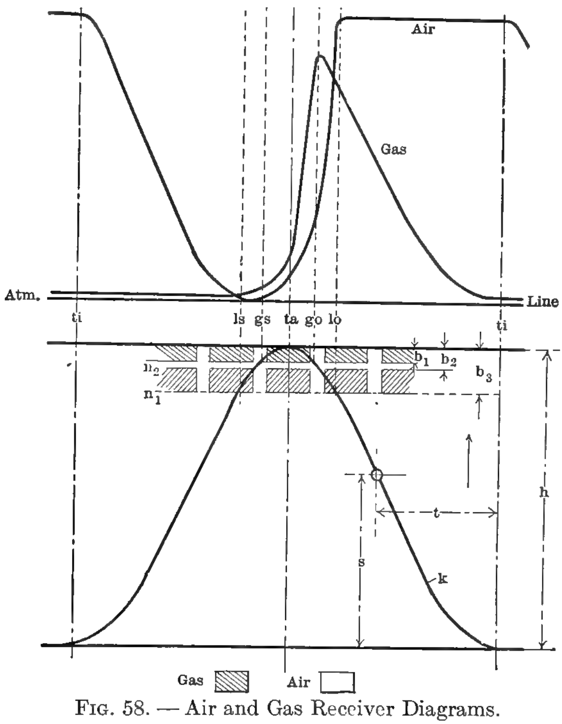


FIG. 58. — Air and Gas Receiver Diagrams.

Through the points of intersection between the lines n_1 and n_2, and the curve k, have been plotted the ordinates l_o, g^o, g_s, l, which show in the upper curves when the piston commences to cover and uncover the respective ports. It is clear that as soon as the air ports are uncovered the pressure in the air receiver drops rapidly. The same is the case with the gas pressure when the gas ports are opened. At the same time the pressure in the air receiver is still further decreased and both constituents enter the cylinder together under variable pressure differences and under

variable area of port opening. In practice the pressure curves show considerable variation, due to undulatory fluctuations occurring in the long pipes connecting the pumps and the receivers, these being produced by the inertia of the mass of gas. This is illustrated in Fig. 59.

In several diagrams taken under variable load conditions there is a considerable difference in the end pressure, which appears to bear an indirect relation to the load factor. To avoid this sort of irregularity the manufacturers have, in the latest types of engines, placed the pumps in immediate proximity to the cylinder. Figs. 60 and 61, give indicator cards from gas and air pumps.

All the conditions which led to the original design of the Borsig-Oechelhäuser engine have now been considered, and the reasons why in this engine the receiver volume is smaller than is advisable for other types, why the receiver pressure may be kept higher and why the pumps are placed directly beneath the engine floor, have been analyzed. It still remains to describe a few more details referring to the mechanical elements and the regulation of the engine, which could not be well understood before the cycle of operation was fully discussed.

Effect of Opposite Piston Arrangement on Engine Dimensions

We have already considered how by the employment of two pistons moving in opposite directions in one common cylinder a double working stroke is secured at every revolution, and what are the advantageous effects on the design of the frame, on the stability of the foundation and on the stiffness of the combined system. There are some other interesting features presented by this unique arrangement of working parts, which make the construction of Oechelhäuser engines so radically different from that of other gas prime movers that it is of importance to devote a few more words to their details.

While the speed of each piston remains quite within the allowable limits of safety, the celerity of separation of the two pistons during expansion becomes very high, in fact double that of the piston speed; therefore, the total distance traveled by both pistons as well as by the gases generated in the combustion

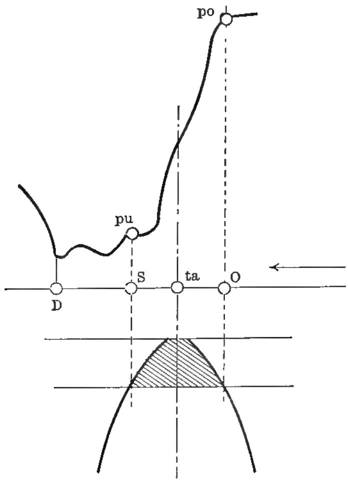


FIG. 59. — Diagram Showing Undulatory Pressure Fluctuations in Overflow Pipes Caused by Gas Inertia.

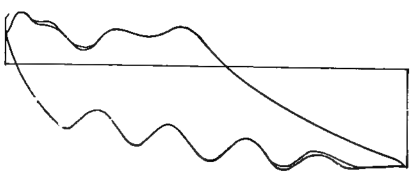


FIG. 60. — Indicator Card from Gas Pump.

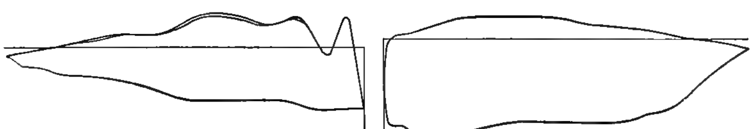


FIG. 61. — Indicator Cards from Front and Back Ends of Air Pump.

process becomes unusually long, while the throw of each crank is comparatively small. The result is that a higher number of revolutions per minute can be employed with normal piston speed, with a small cylinder diameter and long piston travel, a feature that is advantageous for the successful expulsion of the old charge by the new one, without giving the two constituents of the cylinder contents sufficient time for diffusion.

The reduction of cylinder diameter is quite remarkable. For example, in a 500-h.p. engine it becomes 26.5 in.; in a 1000-h.p. single-cylinder engine it becomes 36 in., and in a 1500-h.p. single-cylinder engine it does not exceed 43.3 in.; this latter being the largest single-cylinder engine yet made. The speed varies from 95 r.p.m. in the 2000-h.p. size, to 150 revolutions in the 250-h.p. size. The engines are built for a temporary overload of 20 per cent. and will carry a 10 per cent. overload continuously. It may be mentioned that the masses of this engine are so well balanced that a 100-h.p. engine, running at 125 r.p.m., only requires a 28-ton fly-wheel to limit its cyclic variations to $\frac{1}{350}$.

Cylinder

The cylinder is cast separate from the jacket and consists of two plain tubes meeting at the center and held together by flange extensions of the jacket, which in turn is also composed of two parts connected in the same place as the cylinders and by central flange connection. Thus the cylinder proper can freely expand in the longitudinal direction, and no stresses can occur in the system by influx of heat. It is, therefore, certain to retain its shape, and can be easily rebored when necessary. On account of the cylinders being open, lubrication can be inspected. The oil consumption is, therefore, smaller than in closed cylinders of four-cycle engines. The water space of the jacket contains passages for the circulation of water, which are situated above the cylinder proper; hence the cooling water, entering at the bottom, must first flow around the combustion space before it can enter these passages and proceed to both ends of the cylinder.

The combustion space has the form of a plain cylindrical vessel, closed at the ends by two arched piston heads, and contains only a small starting valve for admitting compressed air, which, of course, is closed when the engine begins regular action.

Hence the clearance space possesses all of the characteristics which contribute to regular and good combustion and also allow nearly perfect scavenging and charging. There are no dead pockets to retain exhaust gases, tarry products or dust, nor are there any projecting surfaces or plates which are likely to produce premature ignition when highly heated.

The two outer casings which surround the cylinder proper, of which one contains the exhaust chamber, and the other the air and gas chambers, form complete castings each with a flange at one end and a light stuffing box and gland at the other end, the latter serving merely to retain the jacket water. As was said before, the two inner flanges are bolted together in such a way that they press together the flanges upon the two cylinder liners and form the joint between them, and also the joint between the liners and the casing at two machined bearing rings on the one side, these rings fitting to the liner and separating the exhaust chamber from the water jacket, and at three machined bearing rings on the other side, of which two form water joints while the third separates the air and gas chambers. While the cylinder liners are free to expand and contract with the changes of temperature, the outer casing is in itself not subject to any pressure beyond that of the cooling water acting internally.

All other details, like the arrangement of inspection doors over the exhaust air and gas chambers, the connection of lubricator tubes, the formation of joints between flanges, as well as the location of the various bosses for indicator, starting valve, ignition plug and drainage, may be studied from the drawing showing a longitudinal section of an engine of 1800 h.p. capacity.

Pistons and Rods

One of the two pistons acts through the connecting-rod and crosshead directly on the center crank of the three-throw crankshaft, while the other is attached by a system of cross-bar and counter rods to the two outside cranks. A special guide is provided at the rear end of the cylinder, which serves to direct the travel of the cross-bar. This bar is provided with a compensating joint which permits accurate adjustment of the separated driving parts, which, on account of the unequal lengths of the two side rods, would otherwise be very difficult, if not impossible, to attain.

The side rods forming the connection between the rear and forward crossheads are made in one length if possible and fitted with nuts at the ends; they have two portions of enlarged section acting as guides. Two light bearings are provided to support their weight and to counteract any tendency to sag. The long pistons are not very different from those employed in single-act-ing gas engines. They are water-cooled, but have single walls, the water space being formed by removable covers, so as to allow inspection of the interior. They have only to carry their own weight and that of some water, while the connecting-rod side thrust is wholly taken up by external guides. The piston head is strongly ribbed; from five to seven rings are provided at the inner end, and three rings at the outer. Cooling water is introduced through telescopic pipes, first into pillars mounted on the cross-bar, whence it flows by means of pipe connection directly into the piston proper and back the same way.

Accessibility

Accessibility of the cylinder interior is secured by inserting between the crosshead and the piston a stumpy piston rod, which is flanged to both parts and can be readily removed. After disconnecting the water-conducting pipes, both pistons may then be withdrawn into the space occupied by the rod and the cylinder inspected throughout the entire length up to the gas, air, and exhaust ports, and without having to dismount any of the driving parts to the engine, nor, of course, any cylinder covers or stuffing boxes. To facilitate this operation, special slides are provided in the crosshead-guide covers, which carry the piston when it is drawn clear of the cylinder. All of the crosshead guides and main bearings are provided with water-cooling devices. The crank-pins of the main shaft are bored longitudinally and tubes led in for lubrication, besides which the usual centrifugal lubricators are employed. All the other parts are, as far as possible, lubricated from central places. The main bearings are oiled on the circulating system.

Effect of Opposite Piston Arrangement on First Cost, Floor Space, and Weight

Regarding cost of manufacture, it must be conceded that the Borsig-Oechelhäuser engine is more expensive to build than

the double-acting four-cycle system. Besides parts like the piston and connecting-rod, three-throw crank-shaft, etc., requiring special care and treatment, and the many forged parts employed, there are three main bearings, three connecting-rods and three crossheads necessary, while for the twin-cylinder combination the number of these parts, including the three-throw crank-shaft, is doubled, of course. Fig. 62 shows the details of a double shaft for side-by-side engines, with the central shaft for carrying an electric generator (English Construction). The outer pins in each case are short, to suit the side connecting-rods, the pull of the back piston being divided between the two pins. The shaft is built from flat web forgings, with cylindrical pin on both bosses. These forgings are all made from fluid-pressed steel. The webs are trepanned and finished to a smooth bore, with the usual shrinking allowances, and are put together by shrinking. The whole shaft is afterward run in a large center lathe and finished true. Body sections and pins are keyed in the webs by means of heavy dowels. The shafts are hollow. The two outer webs are prolonged; by these means the revolving masses are completely balanced. The floor space required by a twin-cylinder Borsig-Oechelhäuser engine is also larger than that occupied by a double-acting four-cycle tandem engine of equal output and of the same coefficient of regulation, wherever the pumps of the two-cycle engine may be placed. The fact that the weight per brake horse-power is very much higher cannot be classified as a disadvantage.

Ignition

While the continental engines of the Oechelhäuser type are mostly fitted with the ordinary magneto ignition, the English engines as constructed by Messrs. D. Stewart & Co., of Glasgow, employ the Lodge system of ignition which was discussed in the preceding chapter. Fig. 63 shows the form of sparking plug used with this system. It consists chiefly of an outer shell, made to fit tight in a water-cooled liner, and an insulated center spindle. At one end is the annular spark-gap, in which the gas is ignited; at the other end there is a small external spark-gap, whose function is to separate the capacity of the leads from the center spindle, and so prevent the possibility of small sparks jumping from the

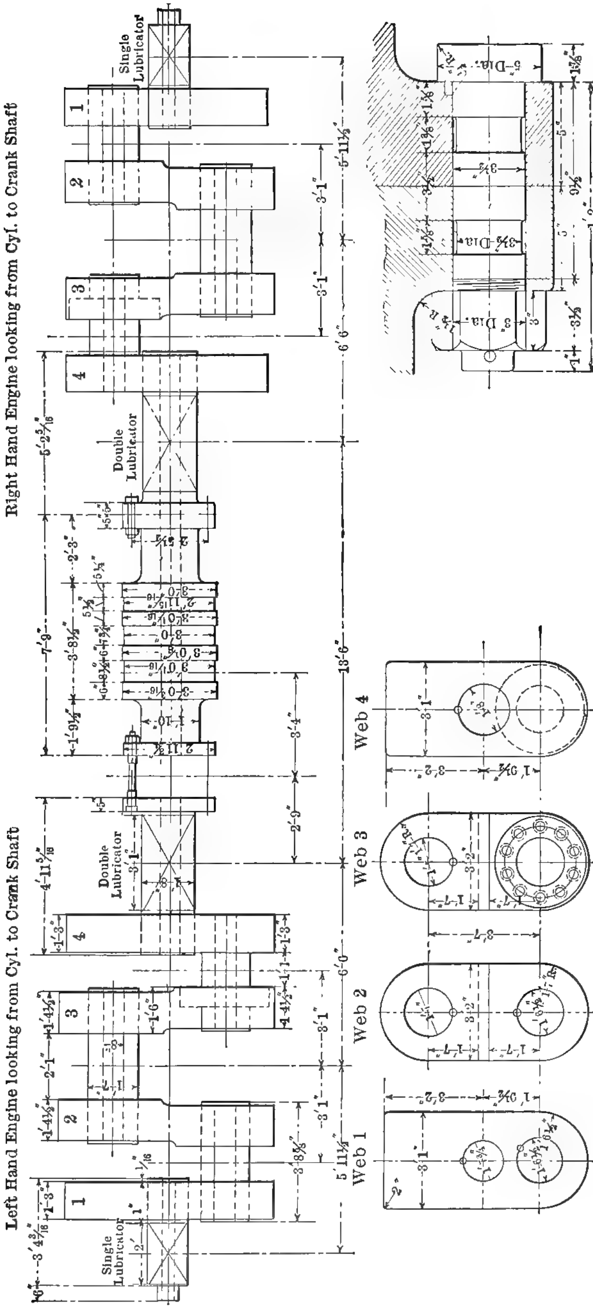


FIG. 62. — Three-Throw Crank Shaft for Twin Engine (English Design).

engine casting to the insulated spindle. The annular spark-gap of this plug offers no points for pre-ignition, and the amount of surface exposed, which would offer considerable opportunity of leakage to the ordinary high-tension current, does not affect this high-frequency spark. The timing of the ignition is effected by a rotating contact maker in the primary circuit One great advantage of this high-frequency ignition is that the timing is absolutely accurate, and can be easily adjusted for different qualities of gas.

The 8-volt battery for supplying the current is connected through a lamp to the mains, and is kept continually charging while the engine is running, this method avoiding all trouble of battery attention; and all that has to be done when starting

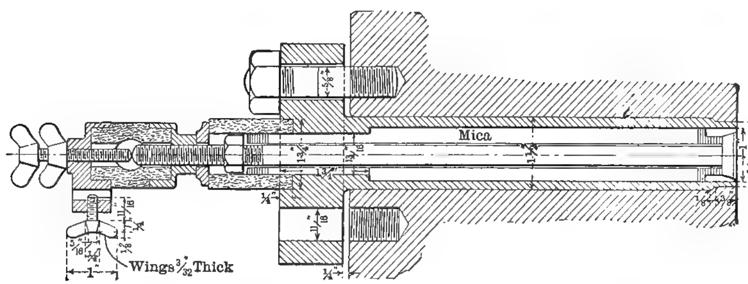


FIG. 63. — Lodge Sparking Plug.

and stopping the engine is to close or open the two switches, shown in the complete diagram of connections, Fig. 64. An important feature of the Lodge igniter is that it is specially adapted to sparking simultaneously at two sparking plugs; and if the plugs be placed on opposite sides of a gas-engine cylinder, the rapidity of ignition, and so the efficiency of the engine, is increased.

In the case of an engine running with light load and rich gas, the mixture near the igniting device might be too poor, since, owing to the arrangement of the inlet ports in the circumference of the cylinder, the gas might be too much distributed within the large mass of air. For this reason an annular slide, controlled by the governor, is provided outside the inlet ports (Borsig Construction). This slide moves easily and cannot get rusted down, as during the working of the charging pumps a

small quantity of oil is continually being carried over and settles on the wearing surface of the slide, thus keeping the latter well lubricated. The annular slide is so adjusted as to close gradually the ports opposite the igniting device when the load on the engine decreases, and to leave only a few openings for the admission of gas when the engine is running without load. The gas, entering the cylinder in the neighborhood of the igniter, mixes only with the nearest particles of air without becoming distributed throughout the large cylinder space; consequently, ignition is always effected with certainty.

Another annular slide is provided outside the air-inlet ports

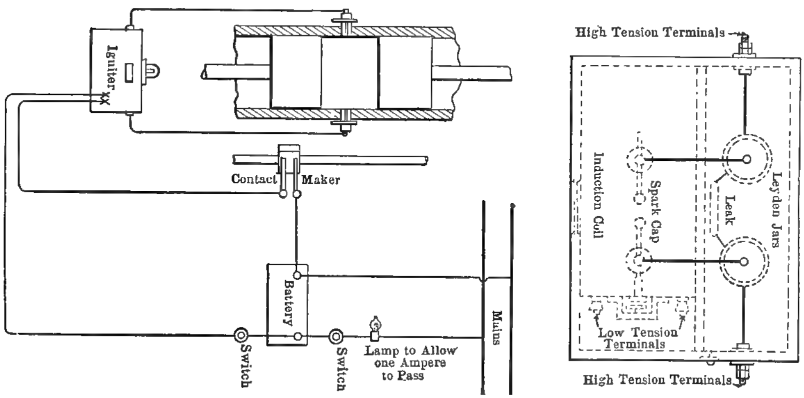


FIG. 64. — Diagram of Connections for Lodge High-Tension Ignition System.

and this is adjustable by hand, so that one can vary the area of port opening according to the quality of gas used. For lean power gases and ordinary regulation the gas slide is also adjusted by hand and not by the governor. These arrangements are indicated by *a* and *g* in the sectional drawing. (See plate IV.)

PUMPS

A few years ago there was a tendency among builders of two-cycle engines to construct the pumps as simple and with as little cost as possible. The result was high pump work and low mechanical efficiency. The present rule is to build the pumps as reliable and perfect as is compatible with economy of manufacture, while complexity of design is regarded as a secondary consideration. In future, the designer must try to combine

simplicity and cheapness with reliability and perfection if he hopes actually to establish the superiority of the two-cycle over the four-cycle engine, which is yet only a matter of theoretical argument.

Reference has already been made in an earlier part of this book to the writer's views on the two-cycle question. As was pointed out in detail, it is believed that the modern high-speed fan, when electrically driven, embodies the advantages of small bulk, minimum floor space, low initial cost, ability to handle all gases, simplicity of construction, reliability of running, elasticity of operation — in fact all points that contribute to the attainment of maximum industrial economy of apparatus or methods. It is only by adopting centrifugal fans for doing the work of scavenging and reloading in two-cycle engines, by centralizing them, and by regulating their output in proportion to the change in quality of gas used and to the varying load on the engine, that the present deficiencies of that type can be successfully overcome.

However, leaving this question out of the discussion and considering the conditions which exist at present, it may be said that the pumps are now mostly made double-acting and are driven from the rear crosshead of the engine either directly or by rockshaft or levers. The location of the pump is determined by considerations of floor space and the requirement, discussed before, that they must be placed in immediate proximity to the cylinder. For blast-furnace work a single double-acting pump is generally used, one end supplying the gas and the other the air. But whenever the volumes of the two constituents differ considerably, which is invariably the case when richer (coke-oven or producer) gases are used, then two separate pumps must be adopted. For the design of charging pumps the same rules and principles must be applied that are fundamental in the successful building of air compressors and similar machines, the aim being the attainment of maximum mechanical efficiency. No special knowledge over what is embodied in ordinary machine design is required.

Figure 65 gives details of the air pump of the Oechelhäuser engine as built in England. The working barrel is a simple cylindrical iron casting, flanged at each end and bored for the working piston, and is bell-mouthed, according to usual practice. It is fitted with a light, hollow cast-iron piston, Fig. 66, with

three Ramsbottom rings, and is designed for working with pressures of from 7 to 8 lb. The pump ends are formed of separate castings, bored and registered to fit the working barrel. Each pump end is divided by a diaphragm into suction and delivery sections. Valves of the Hörbiger and Rogler type are fitted for both suction and delivery.

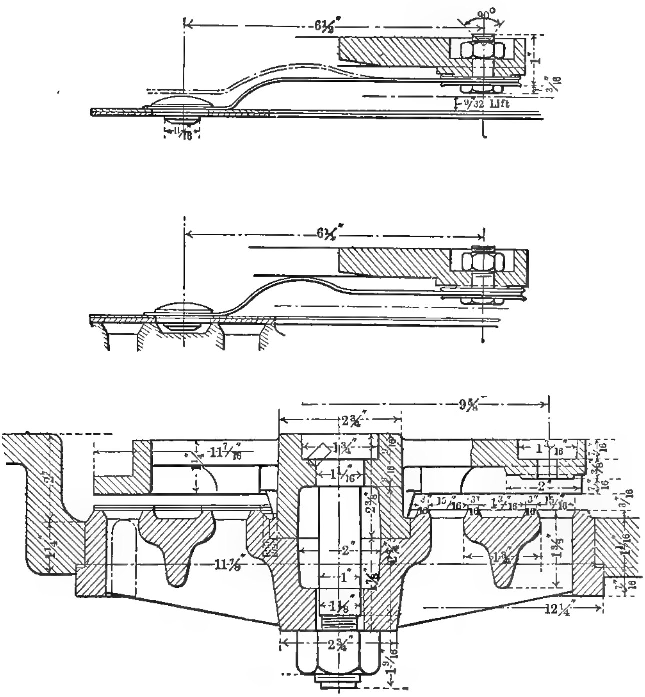


FIG. 65. — Details of Air Pump (English Design).

The details of these valves are illustrated in Fig. 67. Each valve seat is a circular iron casting, having two concentric rings of ports. The guard is a simple cylindrical iron casting, also having passages cored through. A special feature is the arrangement of plates and springs. The valve disk is made of two thicknesses of light plating. In some cases the backing plate is formed of copper. This working valve is secured to the guard by means of three steel springs of flat-bar section, to which a curved setting is given, so that they hold the disk against the

valve face without pressure thereon. The springs are fastened to the steel plates by means of copper rivets, and to the cast-iron guard by means of bolts and nuts. This form of valve stands wear well and works practically silently. The figures show sec-

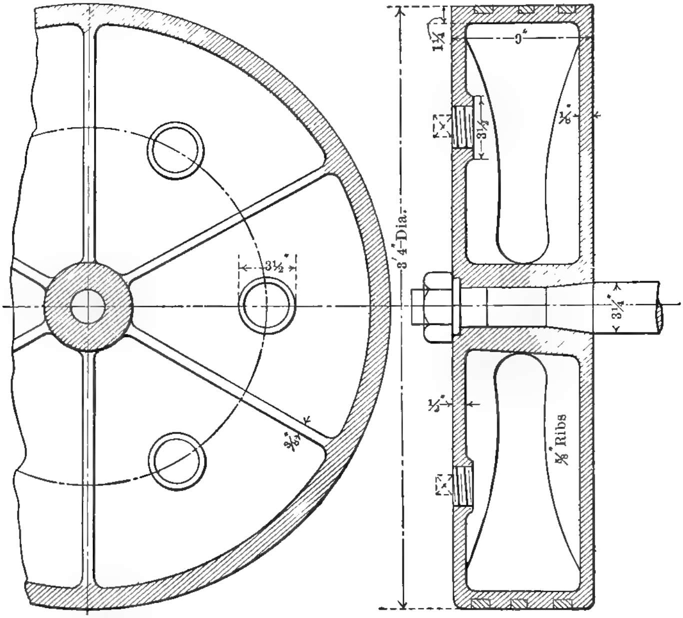


FIG. 66. — Air Pump Piston (English Design).

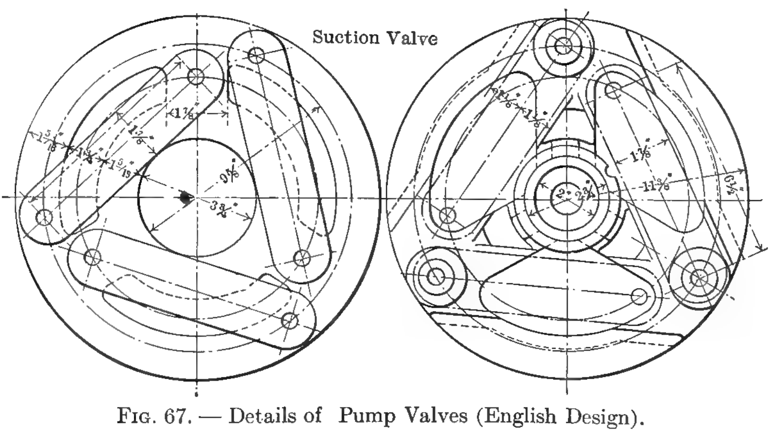


FIG. 67. — Details of Pump Valves (English Design).

tions of the valves on the cast-iron seatings, and indicate the different fixing of the suction and delivery valves; they also show details of the springs and plates, and the connections of the one to the other. The gas-charging pump is generally similar to the air pump already described, except that it is of smaller capacity, in view of the richer quality of gas used in the particular engine we are describing.

Figure 68 shows the pump crossheads, which are similar in design to the main-engine forward crosshead. Fig. 69 shows the mechanically operated return valve.

Mr. Borsig, of Tegel, Germany, has equipped the new pumps which are driven from the engine with such valves as have given good results in his air compressors and steam engines. The automatic suction and discharge valve, shown in Fig. 70, consists essentially of a thin sheet-iron disk, about ½ to 1 mm. thick, weighing about 40 g., and is so cut as to form two spiral arms, secured at the center of the disk by means of two screws, a little clearance being left in order that the arms may be free to move without jamming. Above the disk a valve stop is provided, in which several small helical springs are fastened. These springs serve to load the valve and press the disk firmly on its seat. The point of support of the spiral arms is located in the middle of the valve lift, so that the disk is bent upward. The purpose of this arrangement is to make the stress on the arms as favorable as possible, the strain of the material varying between half the negative maximum stress and half the positive maximum stress. Owing to the very small mass of the valve, its resistance is insignificant. The return valves and their gear are the same as fitted on the Borsig steam engines.

The action of the governor on this valve gear is as follows: The lever *o*, Fig. 71 secured to the rock-shaft *n*, is actuated by the governor. The small eccentric *p*, keyed upon the same shaft, may thus be turned by the governor and the roller *l*, carried by the eccentric rod *q*, caused to take up a new position, whereby the dog *h* is sooner or later pushed off the pallet on the end of the valve lever *e*. To the eccentric arm *q*, at the bend between its fulcrum and its roller *l*, is pivoted the rod *r*, the other end of which is pivoted to the rocker-arm *d*, so that the rod is obliged to partake of the motion of the rocker-arm. By reason of this connection of the governor gear with the active valve gear, the

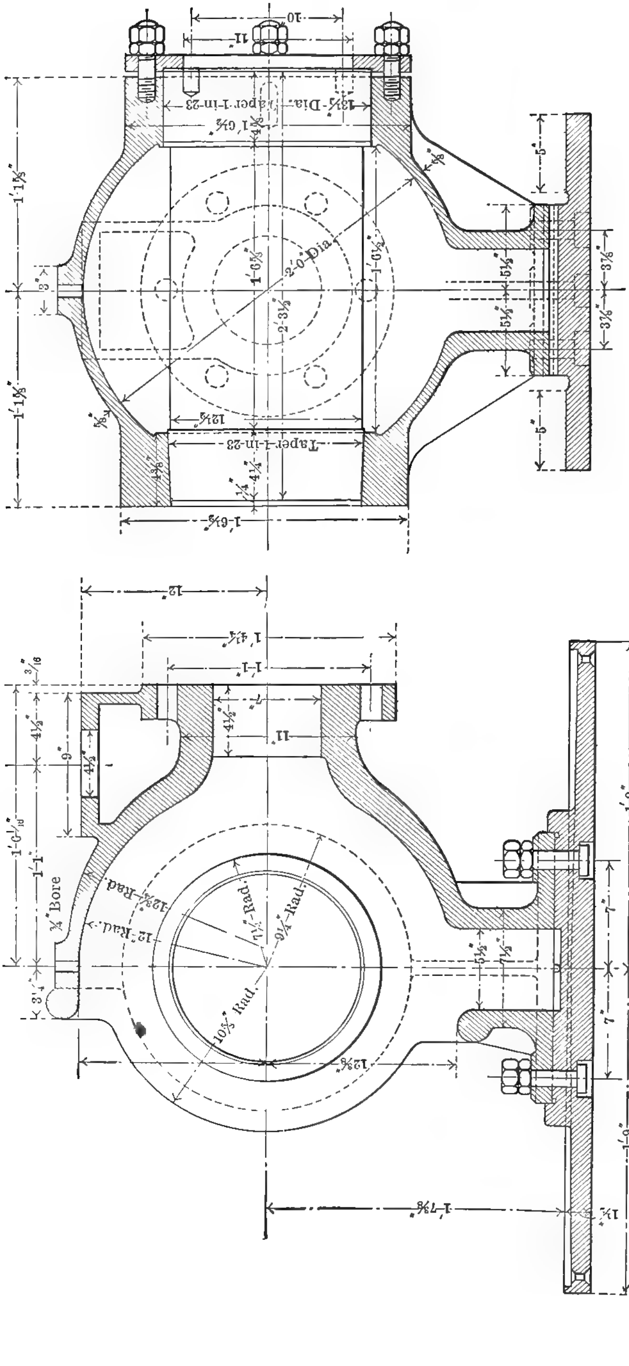


FIG. 68. — Pump Crosshead (English Design).

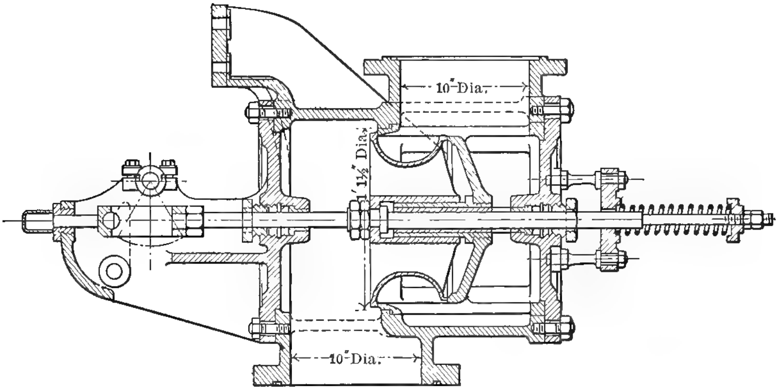


FIG. 69. — Mechanically Operated Pump Return Valve (English Design).

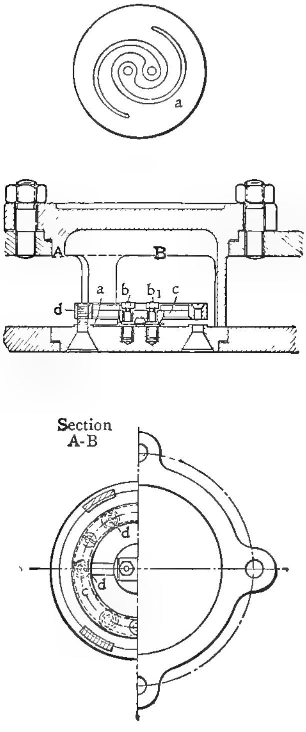


FIG. 70. — Automatic Suction and Discharge Valve for Pumps (Borsig).

dog *h* bears with a wide surface against the pallet, but is suddenly pushed off at the last moment when the return flow of gas and air has been completed.

The engine is also equipped with a gas by-pass and an air by-pass valve, both of which are under the control of the governor and open at the beginning of the pump pressure stroke when the load is decreasing.

Referring to the longitudinal section of the Borsig-Oechelhäuser engine, the starting valve in the center of the cylinder is

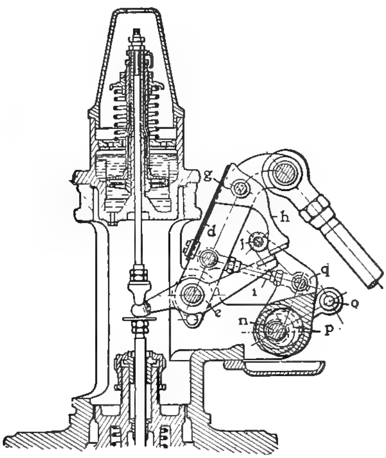


Fig. 71. — Borsig Return Valve.

actuated from the gear that operates the contact breaker of the igniter; *i* is an annular slide on the air receiver, worked from an eccentric on the secondary shaft through levers and rods, and serving to throttle the air supply during the period of charging; *k* and *k* are lubricator tubes and *l*, *l* doors for the inspection of the air, gas and exhaust chambers.

As in most large gas engines, there is provided in the Borsig-Oechelhäuser engine a locking arrangement whereby the starting device cannot be engaged unless a specially marked disk is so adjusted that ignition takes place in the dead-center position of the cranks.

A Test with Coke-oven Gas

After Mr. Borsig took over the patent rights for the manufacture of Oechelhäuser engines, he first installed an experimental plant in his works in Upper Silesia, which has now been in active service for several years. The experience gained with this plant has, of course, been utilized in the construction of the latter types, so that the Borsig-Oechelhäuser engines as built at present show even better economy than was attained with the engine which was tested in August and October, 1903, by Prof. E. Meyer, of the Technische Hochschule, Charlottenburg. Nevertheless that test is of interest. Consideration of the conditions under which the engine in question is working will help to emphasize what has been said in an earlier chapter to the effect that the utilization of coke-oven gas in gas engines is of fundamental importance to industrial interests.

The 500-h.p. gas engine tested in the Borsig works was originally designed to work with blast-furnace gas, and several changes had to be made to adapt it to coke-oven gas. Thus a special gas pump was fitted and the original charging pump, built to pump gas on one side and air on the other, was modified to pump air exclusively. The quantity of air pumped was thereby made too large, and part of it had to be blown off through a valve. The pump work as recorded is, therefore, larger in this engine than in the later constructions, which have pumps properly designed for the conditions of work.

The gas consumption was measured in a Pintsch station gas meter, which was placed behind a gas holder of 423.6 cu. ft. contents serving to regulate the pressure of the gas. The meter was first tested by shutting down the gas-admission valve and watching the gas bell sink down while the gas was flowing out through the meter, the indicator finger of which made one revolution for each 10 cu. m. of gas passing through. The actual quantity of gas leaving the holder, per revolution of the finger, was measured in three successive trials and by three different methods, as 9.9 cu. m. The meter then indicated 1 per cent. more gas than was actually consumed. This must be remembered when studying the results shown in the table. The small gas meter used in the Junkers calorimeter, which served to determine the calorific

value of the gas once every quarter of an hour, was also tested and found to record accurately. Thermometers registering the temperatures of water entering and leaving were exchanged several times without changing their respective records. The variation of the calorimeter was examined and taken into account by increasing the measured calorific value by 1 per cent. All measurements are referred to 0 deg. C. and 760 mm. barometer pressure (29.922 in. of mercury). The number of revolutions per minute was determined every five minutes by means of a speed counter coupled to the crank-shaft. The diagrams, Figs. 60 and 61, were taken every five minutes, fifteen on one card from the working cylinder and ten from the pumps and blowing cylinder. Of course, the springs of all indicators used were carefully calibrated before and after the run. The reducing motion between some reciprocating part of the engine and the indicators was so adjusted that the drum travel was accurately proportional to the piston travel. The cords used were so short that the influence of length variations on the card could be neglected. The indicator on the main cylinder was driven from one of the side connecting-rods of the back piston; the pressures are, therefore, recorded as functions of the travel of that piston. As the front piston has a different travel according to the different length of its connecting-rod, the diagrams taken in the test do not exactly represent the work done in the cylinder. They must be redrawn to a scale which gives the pressure as a function of the relative piston travels. The law of such piston travel corresponds to the law of piston travel for infinite rod lengths, as with such rod lengths the acceleration of one piston is equal to the retardation of the other, for every crank angle. In making these changes on a number of cards, a common correction coefficient was found, namely, 1.1, by which the mean effective piston pressure, as determined from the original diagrams, must be multiplied to get the true mean effective pressure.

As there still exists among engineers a difference of opinion as to the correct definition of the terms "mechanical efficiency" and "thermal efficiency" in two-cycle engines, it may be stated that in the accompanying table the net indicated horse-power of the working cylinder is the difference between the total indicated horse-power and the total work consumed by both of the

charging pumps. Similarly, if the mechanical efficiency is to be a measure of the friction resistances within the machine, then in a blowing engine

$$\eta = \frac{N_w}{Net\ I.H.P.}$$

wherein N_w = the total work done in the blowing cylinder, which is the equivalent of brake horse-power in a brake test. Several analyses were made to determine the composition of the coke-oven gas. Table 3 shows how within a day's time the quality of the gas is changed. It is interesting to study the corresponding change of calorific value which varied from 348.5 B.t.u. to 432.3 B.t.u per cubic. foot, within one coking period of 32 hours.

This variation in the calorific value of generator gas is deserving of a few side remarks. In the present state of gas-engine practice we possess means to determine the speed of an engine at any given moment, we are able to ascertain at a glance the temperature of the cooling water entering and leaving, and we can also easily determine the temperature and pressure of the gas flowing into the engine, as well as the percentage of dust and moisture contained therein; but we cannot by any simple method find out the momentary calorific value of the gas at any time and adjust the engine and generator to changes in conditions. Engineers who are familiar with the working details of gas-engine tests may know that it is possible to observe, directly and continuously, in a Junkers calorimeter, from the thermometer registering the temperature of the water leaving the apparatus, any change in the heat value of the gas, provided the quantity of gas flowing through the burner, as well as the temperature of the water entering, be kept constant. But however valuable this application may prove for experimental measurements, a calorimeter of such subtle construction cannot be made a constant member of an engine-room equipment, nor be intrusted to the hands of the average attendant. What is wanted, therefore, is a simple, reliable, and effective apparatus on the generator or gas pipe, just as is the pressure gage on a steam boiler, which will continuously and accurately indicate the calorific value or the hydrogen content of the gas produced or delivered, and, if possible, will automatically influence the governor of the engine to take care of the new conditions before or by the time the gases

of changed composition and calorific value have reached the working cylinders.

In the test under consideration the cooling water entering and leaving the engine was measured by methods which do not offer anything new over what is known in smaller work. The water consumption was determined as 35.20 gal. total at full load (635 b.h.p), or 5.9 gal. per brake horse-power-hour, the water entering at 22 deg. and leaving at 42 deg. C. This, together with the fact that at normal load and 110 r.p.m. only 16 per cent. of the heat contained in the coke-oven gas was carried away by the cooling water of the working cylinder, is an excellent, and indeed unique, performance for a large gas engine. In another test made in August, 1903, the relation of heat consumption to the load and speed of the engine was determined. It was found that the gas consumption is increased when the load decreases, but only at a slow rate. Thus at 42 per cent. of the normal load 7222 B.t.u. were used as against 6430 B.t.u. at full load. At the higher load the heat consumption per horse-power of work done by the blower proved to be constant between 110 and 68 r.p.m., namely, 9524 B.t.u., average. The quantity of lubricating oil used in the main cylinder was found to be 1.19 lb. per hour. Five drip cups were filled with fresh oil and they consumed altogether 2.7 lb. per hour. The rest of the cups were filled with oil that had been filtered and was used over again. All other important data will be found in the table.

The Ascherslebener Maschinenbau Aktien Gesellschaft is another licensee for the manufacture of Oechelhäuser engines, and these machines show the general characteristics already discussed. The cylinder proper is made of three parts instead of two, the middle portion surrounding the combustion chamber being separate from the ends, but also of cast-iron with a solid wall. The return valves, which are of the König type, are placed in immediate proximity to the charging spaces, one being above and the other below the cylinder. The gas ports are not influenced by the governor and the pump is provided with simple clack valves. The general construction of this engine is shown on the assembly drawings.

TABLE 3

SHOWING VARIATION IN QUALITY OF COKE-OVEN GAS WITHIN 24 HOURS.

TIME	10 A.M.	4 P.M.	10 A.M.
NUMBER OF TEST	I	II	III
Per cent. of CO_2 .... by volume	4.91	4.90	5.30
" " heavy hydrocarbons.... " "	2.63	1.80	2.10
" " O_2.................... " "	0.20	0.30	0.40
" " CO .... " "	11.84	10.60	10.20
" " H_2.................... " "	42.00	48.08	43.80
" " CH_4 .... " "	19.73	18.43	20.30
" " N_2.................... " "	18.69	15.89	17.90

TABLE 4

DIMENSIONS OF 500-H.P. BORSIG-OECHELHÄUSER ENGINE TESTED.

Working cylinder with two pistons	Diameter of cylinder	675.0 mm.
	Stroke of front piston	952.2 "
	Stroke of back piston	947.8 "
	Diameter of cylinder	1140. "
Air pump, double-acting..........	Stroke	500.7 "
	Diameter of front piston rod	90. "
	Diameter of back piston rod	70. "
Gas pump, single-acting	Diameter of cylinder	589.5 "
	Stroke	500.7 "
Blower	Diameter of cylinder	1650. "
	Stroke....................	947.8 "
	Diameter of piston rod.....	150. "

TABLE 5

SOME IMPORTANT DATA FROM TEST MADE OCTOBER 10, 1903, ON A 500-H.P. BORSIG-OECHELHÄUSER ENGINE, WORKING ON COKE-OVEN GAS.

Number of Test		VIII	IX	X	VI	VII
Time of Test		11:40 to 12:00	12:05 to 12:20	12:20 to 1:00	10:40 to 10:55	11:05 to 11:25
Revolutions per minute (mean)		103.0	107.0	106.1	108.2	107.4
Working cylinder	Mean effective pressure, lb. per sq. in.	75.0	73.8	69.3	62.3	62.0
	Total indicated horse-power	821.	839.	780.	715.	707.
Blowing cylinder	Total indicated work done equivalent to brake horse-power	616.2	626.6	574.8	488.	473.8
Air Pump	Mean effective pressure, front	5.09	5.38	5.12	5.56	6.09
	Mean effective pressure, back	3.36	3.58	3.41	3.73	3.94
	Indicated horse-power consumed	68.3	75.2	71.1	79.	84.5
Gas Pump	Mean effective pressure	3.53	3.50	3.58	3.73	3.84
	Indicated horse-power consumed	7.7	7.8	7.9	8.5	8.6
Total horse-power consumed by charging pumps		76.0	83.1	79.1	87.5	93.2
Net indicated horse-power (working cylinder)		733.6	744.4	690.2	617.2	603.4
$\frac{\text{Total pump work}}{\text{Net indicated horse-power}} \times 100$		10.3	11.1	11.4	14.2	15.5
Total efficiency between working cylinder and blower, per cent		76.2	75.7	74.8	69.2	68.0
Mechanical efficiency of blowing engine, per cent		83.9	84.2	83.3	79.2	78.5
Friction horse-power consumed in engine		117.3	117.3	115.4	129.2	129.2
Gas consumed per hour, cu. ft.		13,505	13,951	13,198	12,100	11,800
Lower calorific value of gas (mean), B.t.u. per cu. ft.		398.7	393.1	381.9	393.1	396.5
B.t.u. consumed per hour		5,404,416	5,503,616	5,059,200	4,773,504	4,694,144
Heat consumption	Per total indicated horse-power-hour	6587	6547	6508	6666	6627
	Per net indicated horse-power-hour	7261	7301	7222	7619	7658
	Per brake horse-power-hour, done in blower	8650	8650	8650	9642	9761

VI

THE REICHENBACH ENGINE

It was stated in an earlier chapter that the Nürnberg engine had become the standard construction for large four-cycle work, and the few up-to-date constructions that are at present being built and pushed on the American market by the more prominent manufacturers bear full evidence of that fact. It would, therefore, be useless to discuss further, in detail, any of the various forms of application which the above-mentioned type has found abroad, if it were not for the reason that there are some one or two engine builders of repute who have not been satisfied merely to copy or adopt the fundamental constructive principles that were established by the Nürnberg engineers, but who have, in their latest product, introduced some modifications of design which are apt materially to decrease the cost of manufacture of several elements of the system, as well as to increase their reliability while preserving the general arrangement of parts.

One of the most ingenious constructions built up on Nürnberg lines, but bearing the stamp of original and marked characteristics is the Reichenbach engine, built by Friederich Krupp, and the Union Machine Company in Essen, by the Görlitz Machine Works in Görlitz, and by several other prominent engine builders on the continent. At the Liège Exposition the engine attracted the general attention of engineers and was awarded the grand prize in competition with the most approved continental engine designs.

Frame

From Figs. 72 and 73, showing longitudinal sections of single-acting and double-acting engines, it is evident that the principal features of frame construction are identical in form and in accordance with the requirements discussed before, namely, the crank-

case to be formed between the two main bearing supports, and serving as a receptacle for the lubricant, a guide bed to receive the crosshead, and a circular flange to which is bolted the front end of the first cylinder. In the smaller types, the side walls of the frame are cut down to afford accessibility to the crosshead, while two heavy tie-rods serve to connect the cylinder flange and the main bearings, thus securing fairly central distribution of forces.

In the larger sizes, where the side walls of the frame are so high that it is impossible to get access to the moving parts from above, the top is closed by a solid wall cast with the frame, and serving

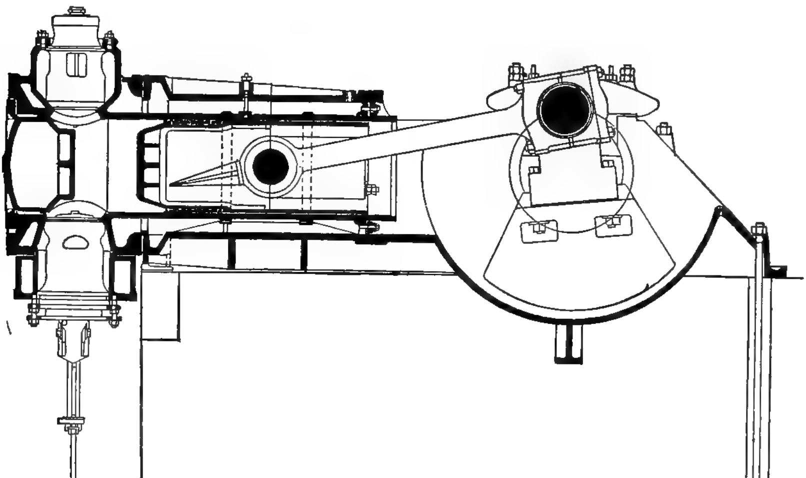


FIG. 72. — Longitudinal Section of Reichenbach Single-Acting Engine.

to transmit all forces applied in front at the main bearings to the circular back flange. In these types accessibility is secured by coring out two good-sized openings in the side walls of the frame, which is in accordance with continental steam-engine practice. Thus the whole casing can be machined by the boring bar with one setting, and requires no other treatment.

To increase the simplicity in design and economy in manufacture the frame of the single-cylinder double-acting engine and that of the tandem type are so constructed as to form the receptacle, water jacket and support for the cylinder liner of the single-acting engine, which liner projects inward, being centered into and connected to the main flange, while a light stuffing box

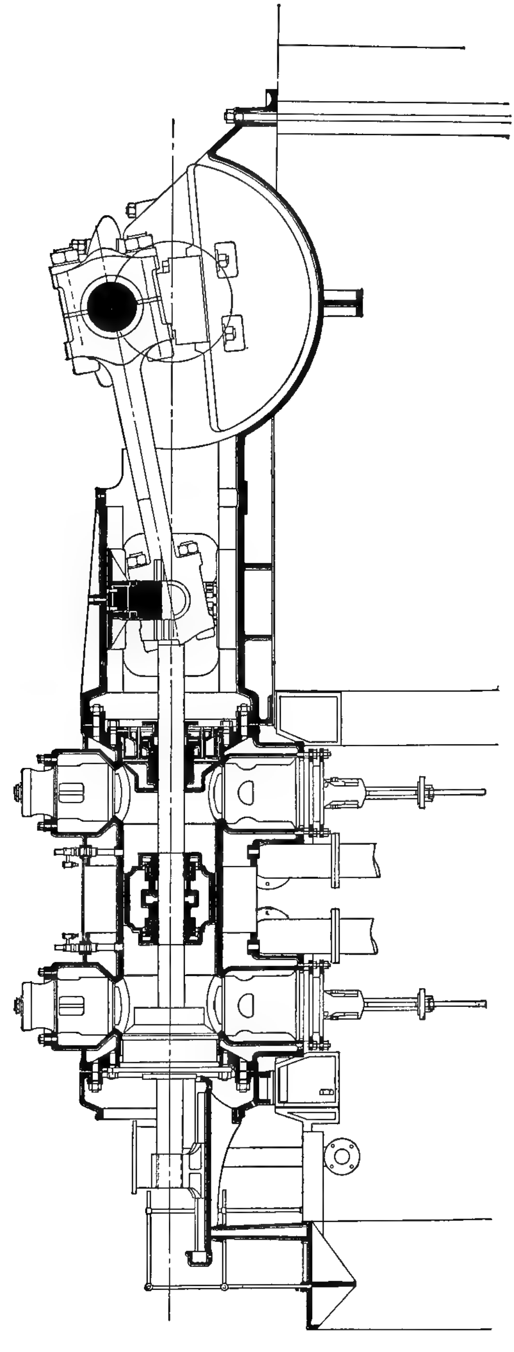


FIG. 73. — Longitudinal Section of Reichenbach Double-Acting Engine, Built by the Union Company of Dortmund, Germany.

and gland are provided in front to prevent the leakage of cooling water.

Thus the one frame pattern serves for all three types of engines, being used the one time as a crosshead guide and the other time as a cylinder jacket.

The frame rests on the foundation along its entire length, being held down by long anchor bolts, while the center piece and tail end are supported by frame plates and can give way to longitudinal expansion and contraction.

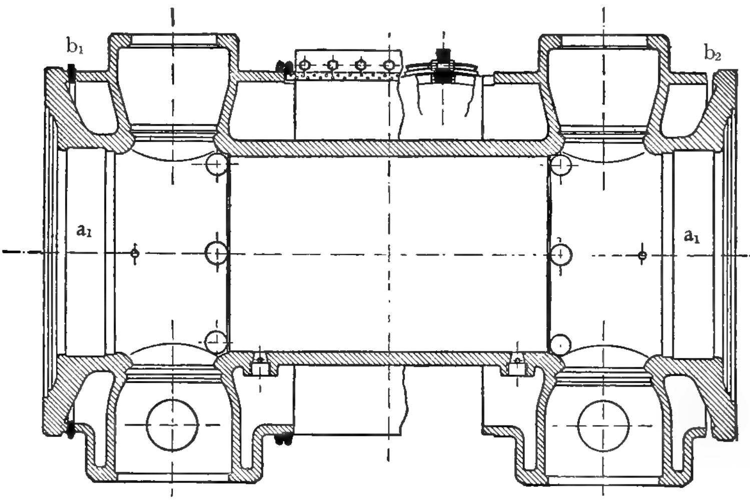


FIG. 74. — Cylinder of Reichenbach Engine.

CYLINDER

The cylinder, as shown in Fig. 74, is cast in one piece with the jacket and has no side lugs or anything to support it but the flange of the main frame in front and that of the center piece or tail end at the back. It therefore forms an absolutely symmetrical piece which can be cast without getting harmful cooling strains in the metal, and which can freely expand in the longitudinal direction. To facilitate this the cylinder is fitted with sheet-iron water casing, the jacket proper being split in two different parts a_1 and a_2, each having an upper and a lower opening for receiving the four valve cages. In the larger types of engines the two parts of the jacket are also separated from the

front and back flanges by peripheral partitions b_1 and b_2, so that they are not subject to the bending stresses exercised by the varying temperature of the inner and outer wall system, as was explained in detail in an earlier part. They are also guarded against the tension forces which are produced by the gas pressure acting internally and which are transmitted by the end flanges, by giving these flanges a tapering form. This cone-shaped flange, with a minimum of flange section, is able to transmit great forces directly to the inner wall without springing.

The two outer slots between the valve cage and the flange are closed by rubber bands which are pressed tight by a wire rope, as shown in detail in Fig. 75. The wide opening between

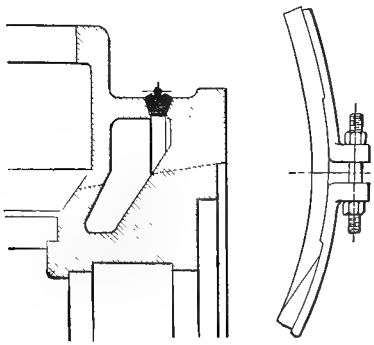


FIG. 75—Closing Peripheral Intersections of Cylinder by Means of Rubber Bands.

the two jacket parts is closed by the sheet-iron casing resting on rubber-packing rings to prevent leakage of water, and held together by iron bands which are tightened by screw adjustment, as shown in Fig. 76. The cylinder covers are secured in place in the usual manner. Together with the piston heads they form an annular combustion chamber, which is a special feature of the Reichenbach engine and which gives a clean compression space having no dead corners or projecting surfaces whatsoever. As was said before, these side spaces or valve pockets are apt, after the completion of the exhaust stroke, to retain residual gases of very high temperature (400 to 500 deg. C.), which do not mix with the charge during the suction stroke, and may therefore during compression produce temperatures of from 1000 to 1500 deg. C., which suffice to inflame the new charge before it is properly

fired by the electric sparker. Therefore, all troubles resulting from premature ignition are in this engine positively avoided.

Piston Rod, Crosshead

Figure 77 gives a good section of the piston and rod and of the system of water cooling employed. Contrary to current

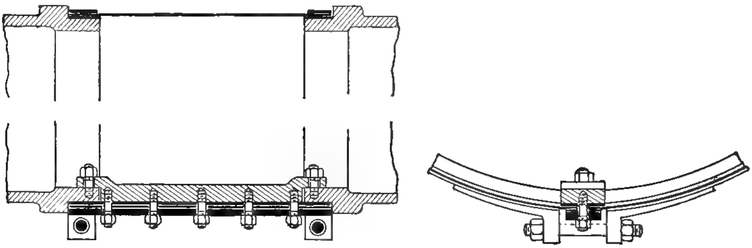


Fig. 76. — Sheet-iron Cylinder Casing.

practice, the piston is secured in place by two counteracting nuts which allow of its removal from either side. Four piston rings fitted with internal springs are employed. The water, instead of entering the piston directly, first flows through the entire length of the rod, returning by way of slots cut in the inner concentric tube in the direction indicated by the arrows. A double mouthpiece, which serves to connect the two inner ends of the concentric

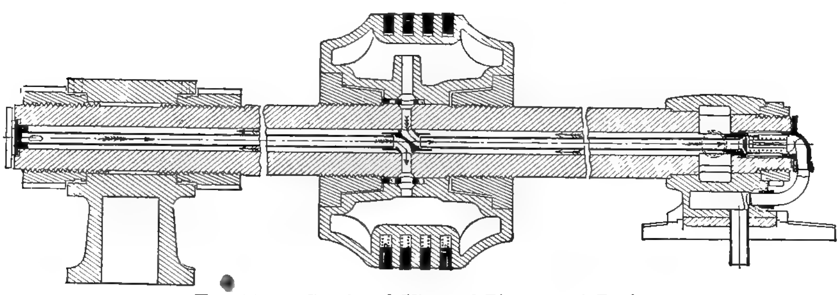


Fig. 77. — Sectional View of Piston and Rod.

tubes, at the same time serves to direct the flow of water into the bottom half of the piston, whence it rises to the top, emerging by means of a tube which is cast in one piece with the inner socket of the piston and through the connecting piece into the tube leading to the back guide head and thence to the water

tank. A check valve is inserted in the overflow passage to prevent any water from turning back.

As is now almost universal practice, the weight of the piston is taken up by external guides so that the piston becomes what it is meant to be, namely, a packing member. There is, therefore, almost no wear of the cylinder liner. The crosshead is of the marine type, allowing the piston rod to pass through if the cylinder cover and piston are to be removed and accessibility to the cylinder interior, inspection of valves, etc., is desired.

There are a few points of novelty and interest to be found in the design of the cross-connecting heads and guides. The great total length of a tandem gas engine, which is often advanced as a drawback when comparing gas- and steam-power installations, and justly so, forces the designer to save in space wherever he can, without, of course, impairing the reliability of any part or the efficiency of operation. While the guiding shoe of the crosshead proper is subjected to various angular stresses exercised by the combined gas and inertia forces, besides the vertical forces acting on it by the partial weight of the piston which it has to support, and must therefore be designed with an ample bearing surface, the middle and back guide heads have to support only the partial weight of two pistons. When figuring on the length of shoe required for these two parts it is found that it becomes very short as compared to the hight, so short indeed that tilting of the shoe is likely to occur. This is avoided in the design under discussion by connecting the upper and lower shoes with the head proper by a swivel joint, which turns around an eccentric bolt, serving at the same time to adjust the exact position of the piston rod in hight. Fig. 78 shows this original arrangement, also how accessibility to the cylinder interior and to the front valves is secured by removing and sliding the front covers clear off the piston on the supporting piston rod. Fig. 79 shows how, by disconnecting the piston rods from the center head and by sliding them through the respective front and back crossheads the two pistons can be easily removed for purposes of cleaning.

Stuffing Box

Figure 80 shows a combination of the Howald and Schwabe stuffing boxes, the latter of which was illustrated and described

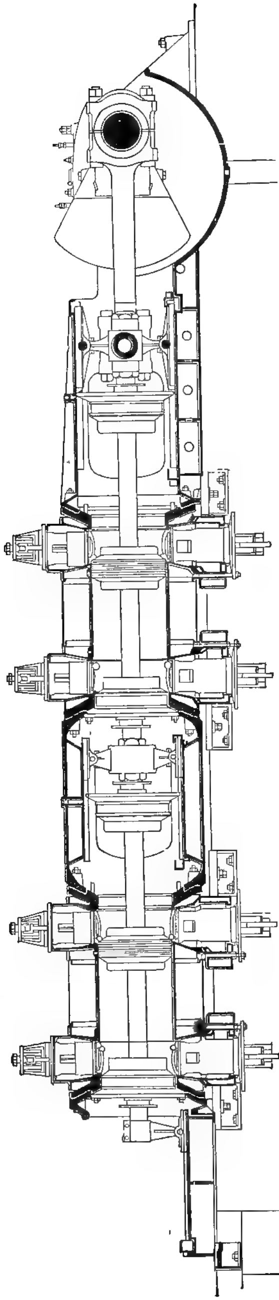


Fig. 78. — Illustrating Method of Getting at Cylinder Interiors.

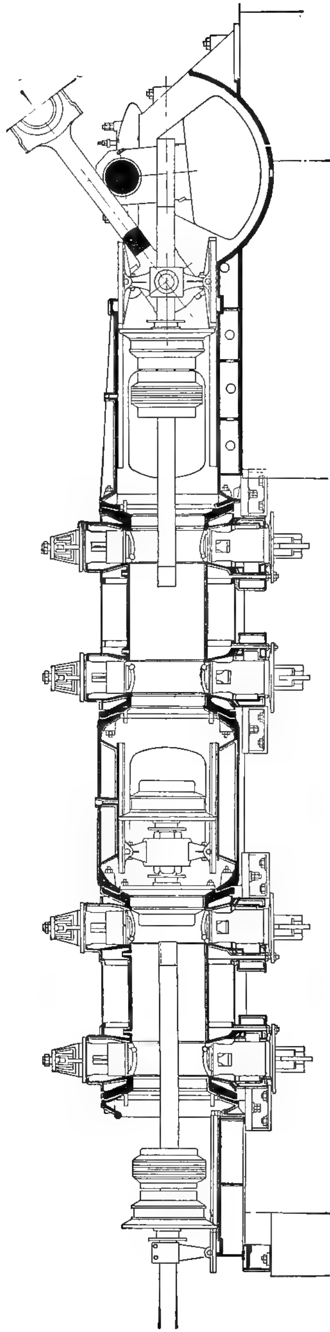


Fig. 79. — Illustrating Method of Removing Pistons.

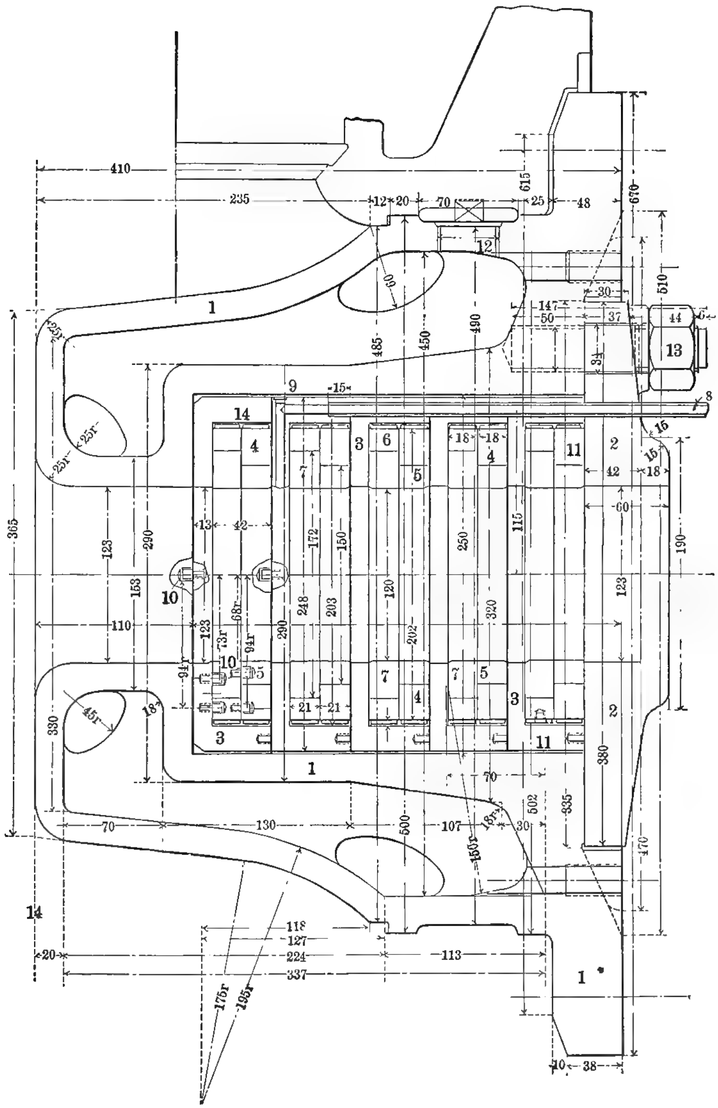


Fig. 80. — Howald-Schwabe Stuffing Box for Double-Acting Gas Engines.

in the Nürnberg section. In this particular construction the space around the rod is filled with square-shaped packing segments, so that gases leaking through will not find any large

spaces to enter and therefore the packing will always remain cool. The whole system is elastic so as to be able to yield to transverse strains, and no unequal wearing of the rod is possible.

The collar segments which form the annular chambers serving for the reception of the packing rings can be readily removed by dismounting the box cover and without having to take out the whole casing. The arrangement of oil feed can be studied from the drawing without further explanation. Lubrication is effected during the outward stroke. No lubrication wigs nor soft metal packing is employed, therefore no adjustment by tightening flange bolts is necessary.

From Fig. 72, showing the single-acting engine, it is evident that to get access to the valves and compression chamber for the purposes of cleaning it is not necessary to remove the piston; it is sufficient to dismount the cylinder cover. Thus it becomes possible to keep the piston very long, so that no appreciable wear can occur, even without using a crosshead, which would be too complicated and expensive in smaller work. Internal cooling of the piston is performed by an air fan, forming the prolongation of the piston rod.

Governing

Before going further into the discussion of constructive details it may be well to consider the system of regulation employed in this engine, as this feature will finally determine the selection and design of the governor, valves, starting gear, igniting apparatus, etc. The question of regulation of gas engines is yet so unsettled, so complex, and so radically different from that which obtains in steam-engine and turbine practice, that a careful discussion of the conditions which control the constructive execution of the regulating mechanism cannot be omitted, especially since the Reichenbach engine offers a solution of the problem which must be regarded as the best that has been advanced up to this time.

It has been said before that the main difference between those qualities of gas and steam prime movers which have a direct bearing on the reliability of service rendered is found in the fact that the first type of engine does not employ in its working process a physically prepared or chemically fixed dynamic medium, but has to form its combustible or explosive mixture for every individual power stroke. The exactness required in the

preparation of such mixture imparts to the governing organs a pronounced significance, for it is obvious that the mixing of the two constituents of the charge bears a very intimate relation to the regulation of the engine, and that any discussion on systems of governing must be founded on or opened from this point of view.

While thermodynamic science has through numerous and careful investigations established definite and precise laws, which determine throughout the whole of its commercial temperature range the generation, the physical properties, and the utilization of steam as a medium for producing motive power, the corresponding actions of combustible gases cannot — with all the admirable work that has been done — be regarded as resting on a similarly reliable basis of experimental confirmation. Besides shortness of time available for research, this instability of convictions and this lack of knowledge are primarily due to the fact that the phenomena involved belong as much to the domain of chemistry as to that of physics and mechanics, and require a great deal more material, capital, and intellect for their solution. This was fully set forth in the chapter on thermal considerations. Now leaving the two first-named difficulties quite out of consideration and just facing the mechanical features of the problem, it is evident that to obtain reliable regulation in any kind of a heat engine, every individual position of the governor must find a corresponding invariable equivalent in work produced, no matter how often or how long this position is occupied. With a ready-made dynamic medium, such as steam, this requirement can be easily fulfilled and with simple means, while with a gas engine, for every condition of load, and also for no load, there must be positive, equal, and uniform ignition of the power charge effected or enforced, which will give, for every like phase of load, cards of equal area throughout the range.

This is the theoretical requirement. Some designers neglect to provide for means of keeping up the same degree of regularity and speed at no load as is observed at higher loads, which is a necessity for the successful operation of generators in parallel. With no system is this operation so difficult to perform as with the so-called hit-and-miss method of regulation, which the writer did not deem necessary to discuss in this book because it possesses, especially for single-acting four-cycle engines, so

many obvious drawbacks, and has now been abandoned by every up-to-date gas-engine builder save one or two firms in England.

With the exception of the hit-and-miss method there is apparent then the principal requirement for all systems of governing, that the mixing of the air and gas must be effected in the engine proper and in such a way that the power charge will ignite under all conditions of load, including no external load. The importance which this factor of inflammability possesses and its relation to the different systems of governing can be best understood when studying the conditions which influence the ignitability of a gaseous mixture. From what has been said before, we can summarize as follows: A specific gaseous mixture of definite and uniform composition will ignite the earlier the higher it is compressed before ignition. And, uniform mixtures of equal compression but unequal proportions of the two constituents can be ignited the better the richer the contents of combustible gas in the mixture, up to a certain limit.

Without repeating what has been said under systems of governing, it will be remembered that there are three different methods, namely, the quantity, the quality, and the combination method. The drawbacks of the first were found to lie in the fact that for low loads the quality of charge required per power stroke becomes so small that only a very low degree of compression is obtained, which impairs the combustion efficiency of the charge and sometimes arrests its inflammability altogether. The second method shows this disadvantage, that owing to unavoidable molecular disturbance of the gases passing the inlet, layers are formed of varying thermal composition which will give varying rates of flame propagation and inflammation when the mixture is ignited in the engine cylinder. This fact finds its visible expression in the divergence of indicator cards and the uncertainty of ignition effected at no load. Thus with engines employing the system of pure quality regulation it is possible sometimes to obtain for equal and fixed positions of the governor indicator diagrams of unequal area and, therefore, different equivalents of work done. Although this system is from the thermal point of view the most promising and efficient in the present stage of our knowledge, no mechanical appliances are available which would allow us to realize its advantages for all gases and loads, even if early or

continuous ignition, high compression, and provocation of ignition at several points of the gas were employed.

The simplest method of economical regulation is to dilute or weaken the mixture as far as is compatible with the inflammability of the special gas used, and from this point down to reduce its quantity. Several firms have now adopted this practice in their latest designs, but Reichenbach was the first to recognize

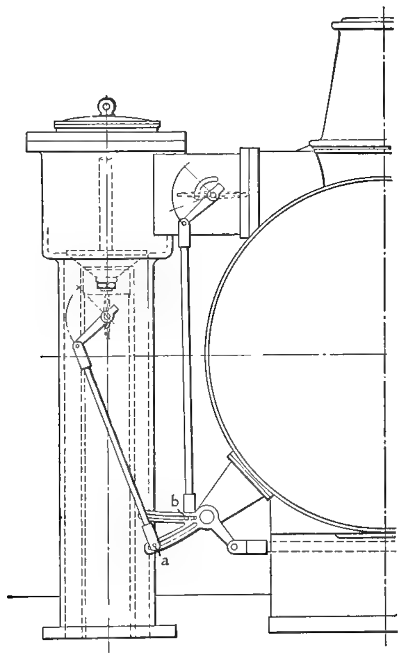


FIG. 81. — Reichenbach's Device for Combined Quantity and Quality Governing.

the possibilities offered thereby, for as early as 1899 we find his large experimental coke-oven gas engine built in Marienfelde-Berlin constructed along these lines. Fig. 81 gives a view of the arrangement used on that engine. The double-arm lever *b* is operated from the engine governor and is provided with slots, one of which, *a*, serves to operate by a lever and rod the gas- and air-admission valve, thus regulating the quality of the charge, while the other, *b*, serves to actuate the mixing valve, thereby varying the quantity of the mixture admitted. The two slots,

or rather the respective sleeves gliding therein, bear a peculiar enforced relation to each other, in that if one of the two slides is without, the other is within. Thus if *a* occupies its extreme outward position the result is pure quality regulation, as the distance traveled by *b* is insignificant. If, on the other hand, *b* takes the extreme position without, there is pure quantity regulation. Each intermediate position gives a certain combination of both systems of governing. If, therefore, an engine is to run on some gas of unknown quality or characteristics, we shall have to begin with quality regulation; in other words, shift the sleeve into the extreme outward position, and as soon as misfiring begins at the lower loads, the sleeve has to be shifted back until firing occurs regularly at each power stroke. By sliding the sleeve *a* back, the sleeve *b* travels in an outward direction and quantity regulation becomes more and more preponderating, which is the less economical of the two methods, but always gives, with a sufficient degree of compression, guarantee of positive ignition. If certain other conditions or requirements demand a modification of the theoretical combination outlined, such modification can be easily obtained, as the mutual position of the various parts can be so adjusted as to suit every individual case.

Experiments with this arrangement were made on two engines of equal output, one using illuminating gas of high heating value, and the other producer gas having a very much lower calorific value. The tests demonstrated a necessity which becomes apparent with even very little consideration, namely, that if the quality of charge decreases the point of ignition must be automatically advanced in order to give the slower burning mixture sufficient time to complete its combustion at the smallest volume, and to prevent after-burning being carried too far and unburned gases being discharged into the exhaust. The results of these experiments emphasize the necessity that the three main factors which determine the thermal efficiency of internal-combustion engines, namely, air, gas, and ignition, must be regulated from the governor of the engine, and that the adjustment of none of these factors must be left to the attendant, on whose intelligence the manufacturer cannot give a guarantee to the purchaser. It is obvious that such automatic action is very much superior to the personal equation, which should be elimi-

nated in the operation of gas engines whenever that is practically possible.

As was pointed out before, it would be useless to provide for elaborate means of governing where only a crude regulation is required, and also to pronounce one fixed system or the mechanical means of its execution as the only one that must be applied under all conditions. But since there is now no longer any limitation in the applicability of gas-engine drive, whether for direct- or alternating-current generators, blowing engines, rolling mills, pumping engines, or air compressors, it is desirable to have one system which will adapt itself to all the various drives with the minimum amount of adjustment required.

That a practical solution of the governing problem has not been found earlier has its sole reason in the fact that the large gas engine has had a very limited time for its development, scarcely six or seven years, so that even in the present state of high perfection the possibilities for further improvements are enormous.

When using gas engines for driving blowers, pumping engines and compressors, which often have to work at widely variable speeds, sometimes as low as 30 r.p.m., it goes without saying that ignition must be effected later than at the normal speed (100 to 150 r.p.m.). It is also obvious that the operation of retarding and timing the point of ignition should not be intrusted to the hands of the attendant who, by some mistake or other, may advance the timing gear to give premature ignition, whereby such excessive pressures may be produced as cannot be taken into account when designing the engine, so that disastrous results are likely to occur. It has, therefore, been proposed to provide engines of this kind with a second governor, which may be combined with the main governor, and arranged to accelerate ignition within the maximum and minimum rates of revolution. The auxiliary governor will, of course, effect the retardation of ignition when starting the engine, as at that time the speed is very low.

With this engine it is also possible to use gases of very low and varying calorific value, as, through the automatic action of the governor provoking ignition at the proper moment of the stroke, even the poorest gas has sufficient time for complete combustion. Premature explosions, which with some engines occur during the suction stroke, and misfires are impossible

with this arrangement of enforced relation of the three power factors.

There is also better balancing of the reciprocating masses obtained at low loads, as the rising pressure of combustion re-

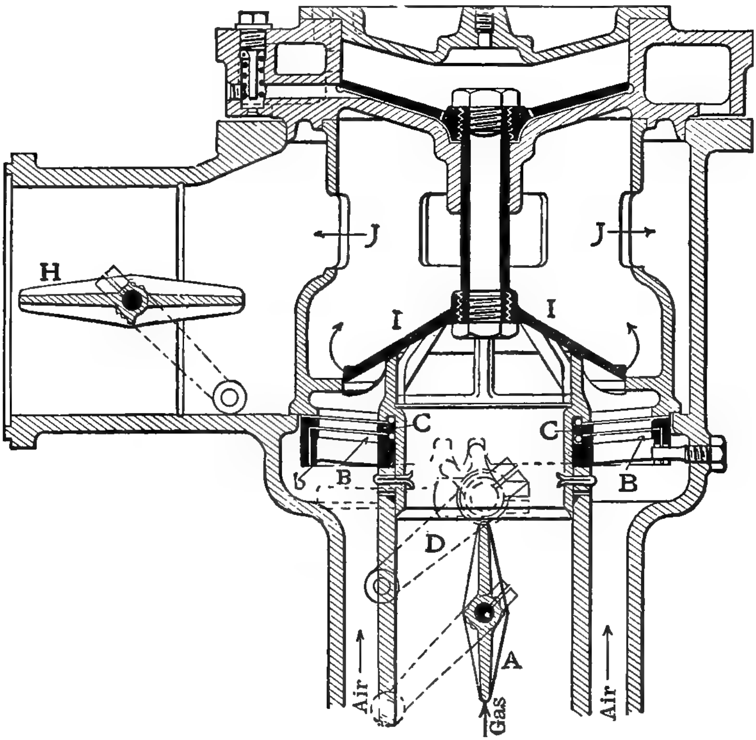


Fig. 82. — Reichenbach's Arrangement for Premixing and Regulating Air and Gas.

places the decreasing pressure of compression in due time and earlier than with pure quantity regulation.

Premixing the Power Charge

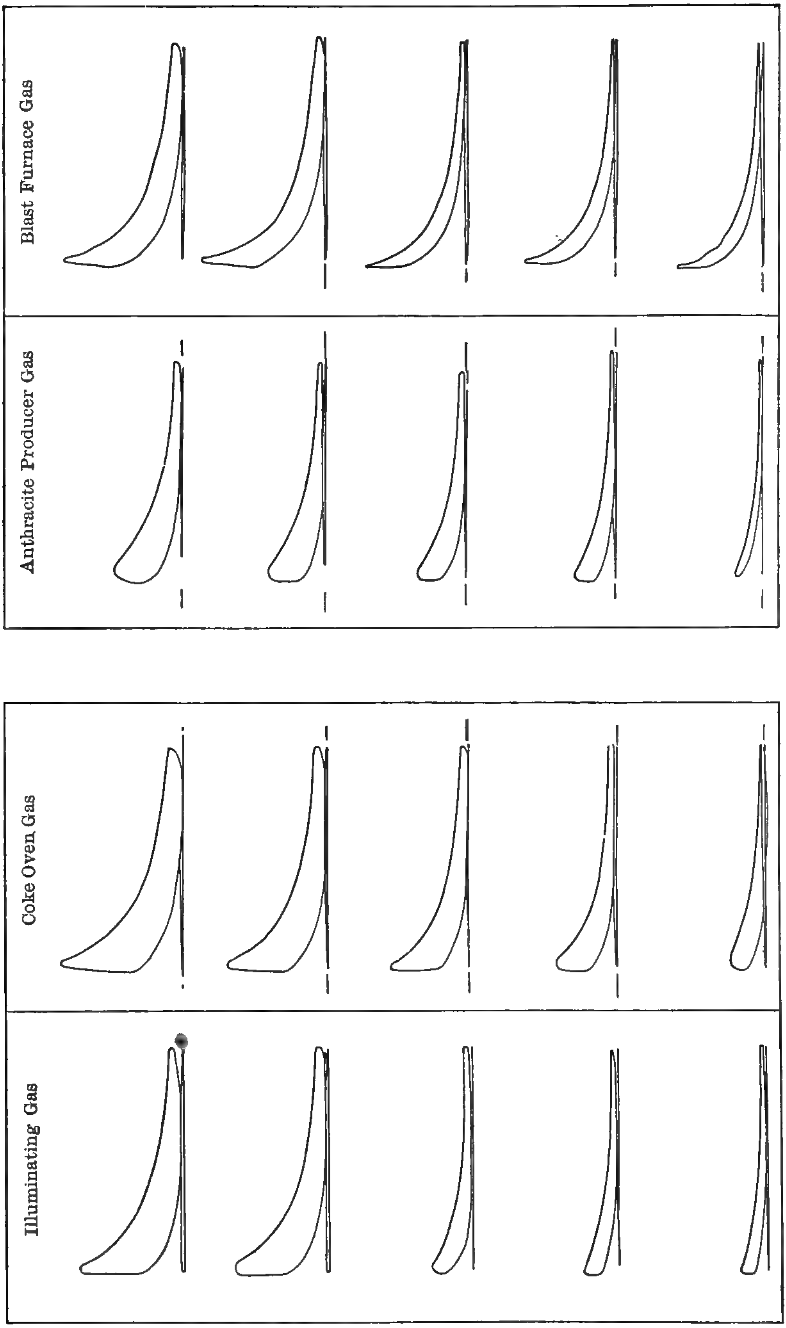
In the Reichenbach gas engine, previously described, the charge of gas and air is mixed prior to its entrance into the combustion chamber by means of a special automatic mixing valve, illustrated in cross section by Fig. 82. A simple butterfly valve *A* controls the supply of gas, while the air supply is controlled by two

rotating disk valves or dampers B and C. The disk B is rotated by hand through the medium of a lever D and a toothed segment meshing with teeth on the under edge of a vertical flange b, around the outer edge of the disk B. The disk C is operated by the governor through a similar intervening mechanism, not shown. The air and gas are mixed by a cone-shaped buffer, plate I, from beneath which the mixture emerges to the intake chamber J, whence it passes through ports to the admission pipe in which is provided a throttle valve H, controlled by the governor to suit the requirements of the load. The quality of the mixture is adjustable by hand to suit the quality of gas being used at any time, and once adjusted for this, the governor takes care of all other adjustments.

Owing to the excellent combination of quantity, quality, and ignition governing, with means for enforcing a uniform mixture of the two charge constituents, it is possible in the Reichenbach engine to employ successfully gases of very low calorific value and of varying thermal composition, such as blast-furnace and coke-oven gases. Figs. 83 and 84 show a series of indicator diagrams taken from this engine when using various gases and under various loads. They testify for themselves, better than any explanation can, to the superiority of the new system of regulation over methods hitherto employed. The speed fluctuation of the engine, which is the range between the maximum and minimum numbers of revolutions per minute, is also very low, namely 4 per cent., and usually less. Of all engines which have so far been subjected to actual working tests and of which results were made public, the Reichenbach has proved to be by far the best governed.

Valves and Valve Gear

There was evidently a laudable effort on the part of the designer of this engine to make these parts readily accessible and easy to remove, without having to take down any pipe connections. Fig. 85 shows the arrangement by which the exhaust valve and cage are suspended on three wire ropes having one common counterweight for balancing these parts. By unscrewing only one bolt of the valve gear the cage can be dismounted and lowered to the bottom of the pit, remaining suspended vertically all the while during removal. In one of his engine designs Reichenbach



FIGS. 83, 84. — Indicator Cards from Reichenbach Engine Working with Various Gases and under Varying Loads.

has exhibited a bold departure from recognized practice in changing the respective position of inlet and exhaust valves, that is, placing the former at the bottom and the latter at the top of the combustion chamber. His reasoning is that as it is not absolutely essential to cool the inlet valve, this can be given the simplest possible form, such as that shown in Fig. 86. A valve of this type hardly ever requires cleaning or repair, provided that the gas used in the engine is cool and clean; hence the position under-

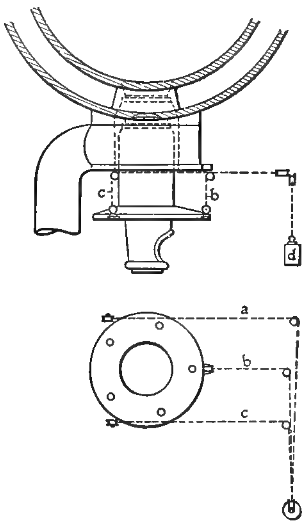


FIG. 85. — Method of Suspending and Balancing Exhaust Valve and Cage for Quick Removal.

neath the engine, where it is hard to get access to it, is not so disadvantageous for the inlet as it is for the exhaust valve.

Being the most vulnerable organism of the gas engine the exhaust valve must invariably be water-cooled; this is also true of the valve cage, where the solid products of combustion are apt to settle. The motion of the exhaust-valve gear, which is linked to the head of the cage, exerts much heavier stresses on the system than that of the inlet valve, having to open against high internal pressures (40 to 60 lb. per square inch), unless it is balanced, so that also for this reason it seems better to have the exhaust valve on top of the cylinder, easily accessible and where it can

be readily removed by the traveling crane. Moreover, when exhaust valves are to be balanced satisfactorily, and if pistons are employed for packing instead of double seats, it is found that the latter wear out very fast, as dirt and oil are apt to drain into and clog up the balancing chamber and the passage leading to it. With the exhaust valve on top of the combustion chamber, clogging up of the balancing piston is less liable to occur since the passage and chamber are apt to empty themselves of the foreign matter and keep clean. In order to get rid of the surplus oil and other tarry impurities which settle at the bottom of the combustion chamber around the inlet-valve seat, a blow-off pipe *b* and a cock are arranged as in Fig. 86, allowing the removal of the dirt in a similar manner to that in which the condensation is drained from the cylinder of a steam engine.

An unusual feature of the valves illustrated in Figs. 86 and 87 is the employment of very short and strong instead of long and flexible springs, it being held that short springs are only very slightly deformed by the valve lift and are more reliable and of longer life than the others. Of course it is only by using a combination system of governing that this is made possible, since with quantity regulation the depression existing in the cylinder at the beginning of the suction stroke when the engine is running at no or low load is so great that very heavy springs are needed to prevent the valves from being automatically lifted from their seats by the suction effect of the piston. The arrangement of the rolling levers and other parts of the valve gear is such as to eliminate entirely the effort of the springs on either the valves or the gear. The valve is first closed mechanically and thereafter the pressure of the spring is allowed to bear against it. The action of the rolling cam levers prevents any undue back pressure on the secondary shaft and eccentric, and no separate springs are required to balance the weight of the oscillating masses.

In the Union engine exhibited at Liège the radical change just discussed had not been introduced, the inlet and exhaust valves being mounted on the top and bottom of the combination chamber respectively and constructed as shown in Figs. 88 and 89. The valve stems are very large in diameter and have a liberal length of guide; the latter is, for the exhaust valves,

also water-cooled. The total length of the valves has been considerably reduced. The valve cage *c*, on the upper end of which

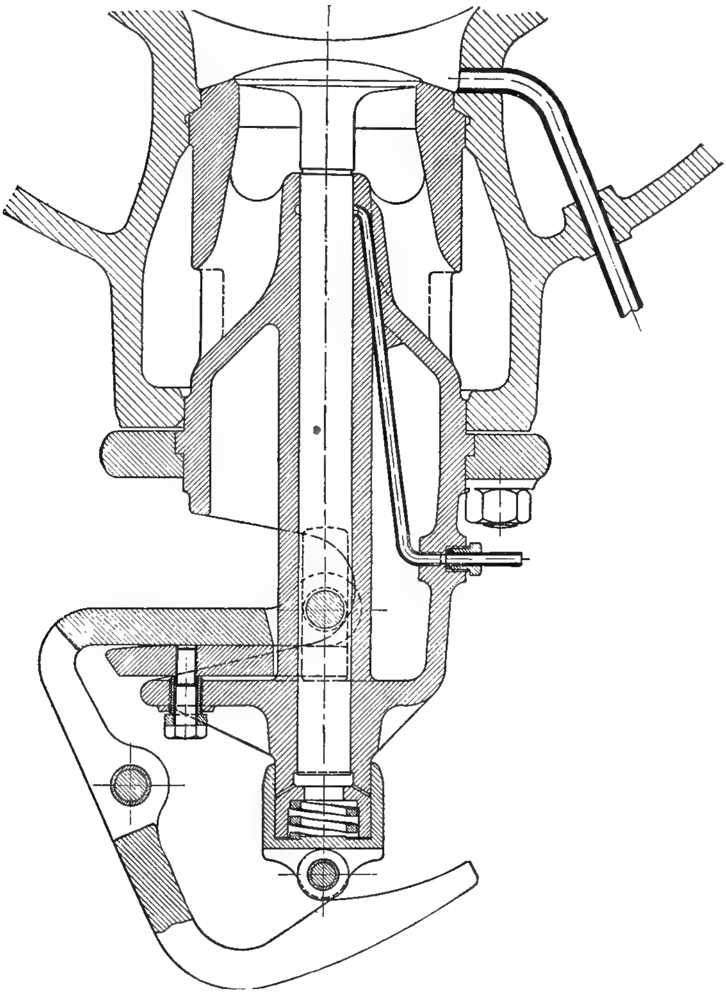


Fig. 86. — Arrangement of Inlet Valve at Bottom End of Cylinder (Reichenbach).

are the fulcrums of the rolling cam levers *d* which serve to actuate the valve stem by means of rollers *r* interposed between them, is mounted in a circular opening in the water jacket *j*. Both

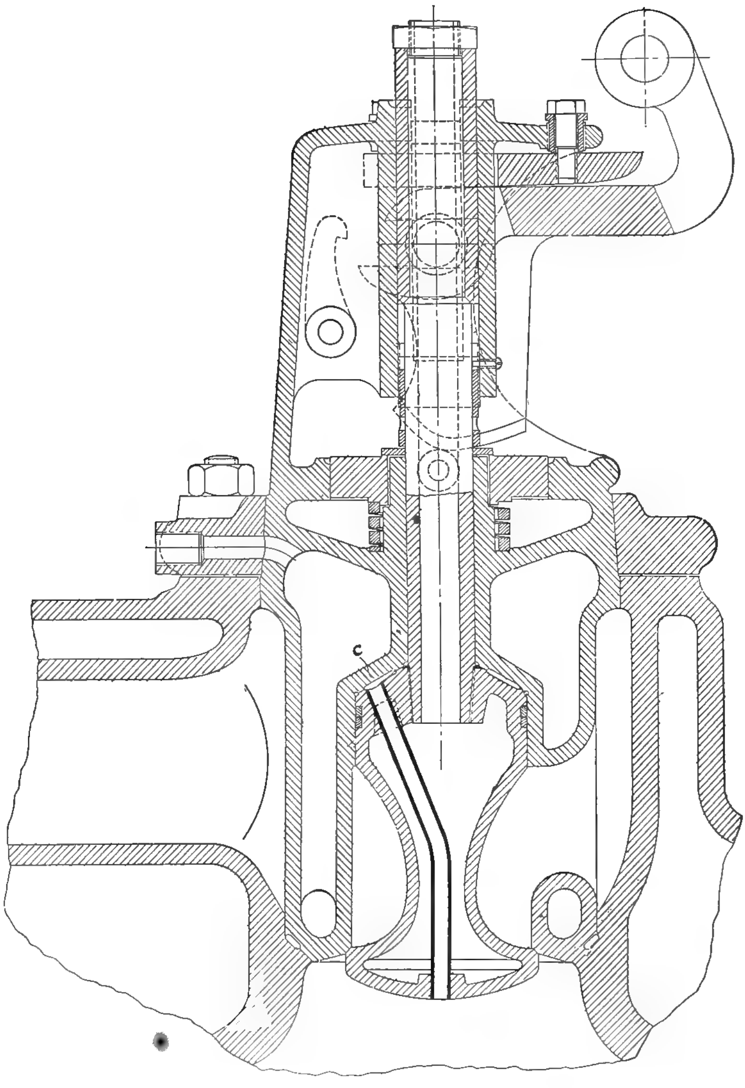


Fig. 87. — Exhaust Valve on Top End of Cylinder (Reichenbach).

inlet and outlet valves are cooled very effectively. An important feature in the construction of the exhaust valve is that by loosening a single connecting bolt *b*, Fig. 89, the valve proper can be removed toward the interior of the cylinder for cleaning or grind-

ing purposes, and without having to dismount the valve cage or gear. In connection with what was said about valves in an earlier part of this book, all other details, such as introduction and outlet of the cooling water, lubrication, etc., can be studied from the accompanying drawings without further explanation.

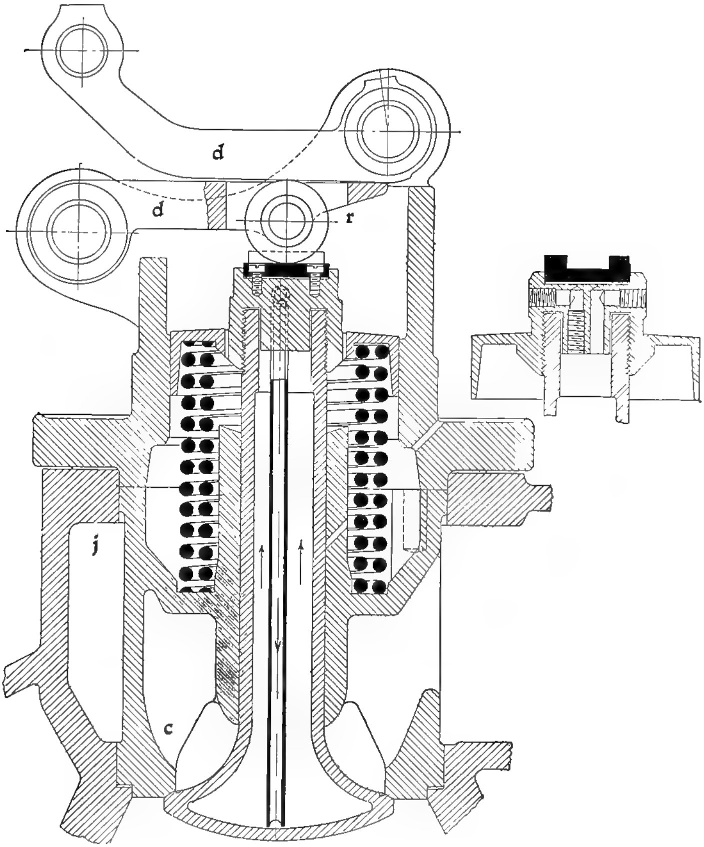


FIG. 88. — Inlet Valve of Union Engine (Reichenbach).

The much discussed question of cams versus eccentrics has been solved by Reichenbach in a very simple and efficient way, namely, by employing for each end of the cylinder a single eccentric mounted on the lay shaft. It serves a variety of purposes: to open and close the inlet and exhaust valves, to operate the two igniters, also the starting valve and the mechanism for preopening

the exhaust when starting. The combination of all these actions is very clearly illustrated in Fig. 90, which shows the actuating of the inlet and exhaust valves by means of rolling cam levers

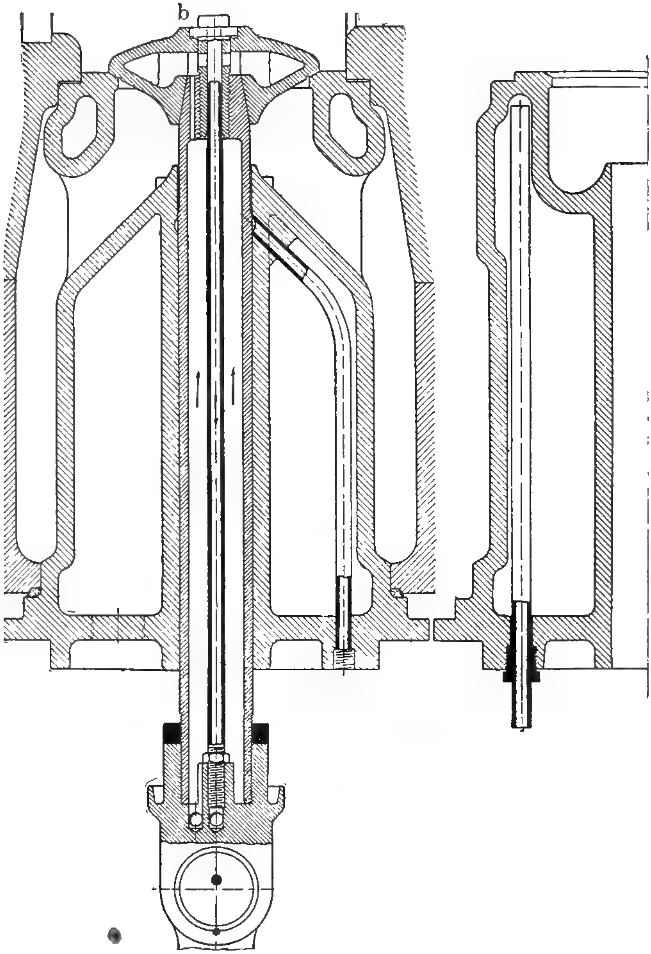


FIG. 89. — Regular Exhaust Valve (Reichenbach).

and curved disks, as well as the operation of the two Bosch electric igniting magnetos by means of an igniter gear which is adjusted according to the load to give earlier or later ignition, as described before. For multiple-cylinder engines the Bosch magnetos are combined in a single unit. The igniter barrels can be

readily dismounted so as to be able to clean the sparker from moisture or coatings of lubricating oil which may interfere with its proper working. In general the valve gear is designed on the same lines as are those of modern continental steam engines; in fact the points of similarity are not restricted to this one feature. Fig. 91 gives a diagram of the phases of operation of the valve gear, from the eccentric. It must be mentioned as a disadvantage that inlet and exhaust valves cannot operate independent of each other.

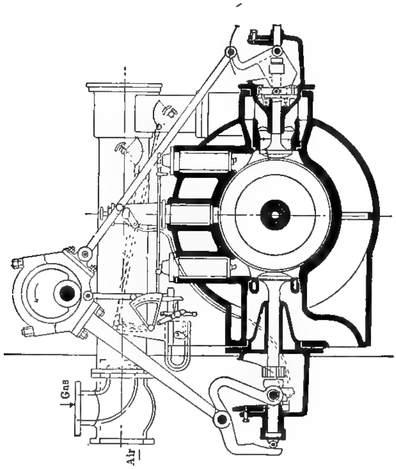


FIG. 90. — Reichenbach Arrangement for Actuating Valves, Igniters and Starting Mechanism from One Eccentric.

An interesting feature peculiar to the Reichenbach engine is that the governor is not driven from the cam shaft, as is done ordinarily, but is mounted directly on the end of the crank-shaft. As stated before, this practice is quite commendable since the stresses and vibrations to which the cam shaft is subjected when opening the exhaust valves are very severe and must have a bad effect on the quiet working of the governor; also the governor gear and shaft are apt to wear out quicker. When the governor is driven directly from the crank-shaft, which is by far the cheapest method, then a long rod is necessary in order to reach the valves, but this rod can be kept very light, being subjected only to torsional forces. If no room is available on the crank-shaft the governor may either be driven by an independent gear from it,

or it may be driven from the lay shaft gear by a separate concentric tube, as shown in Fig. 92, which does not receive the torque nor participate in the vibrations of the cam shaft proper.

The mechanism for relieving the compression when starting, as well as that for operating the starting valve, is shown in Figs. 93 and 94. It is known that for starting the engine with compressed air the exhaust valve must be opened during the

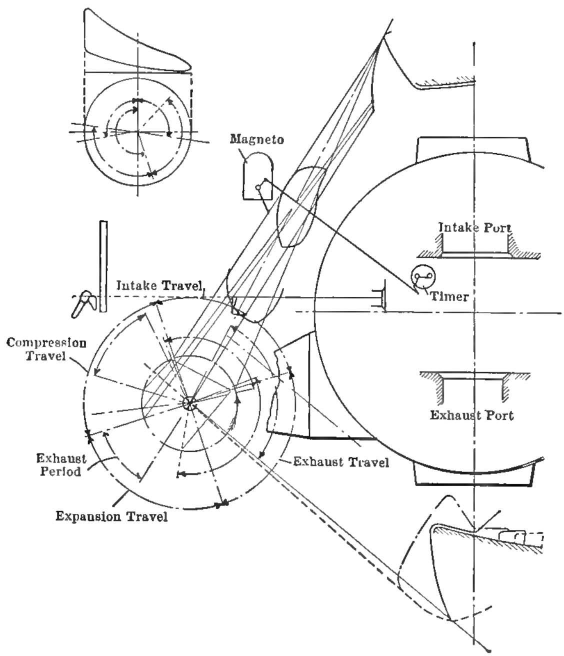


FIG. 91. — Diagram of Valve Gear Operation from Single Eccentric (Reichenbach).

return or compression stroke of the piston in order to allow part of the gases contained in the cylinder to escape, so that the rest of the charge is subjected to a compression of only a few atmospheres. Therefore, in the engine under discussion, it is necessary first to adjust the starting gear so as to transform the four-cycle into a two-cycle action. This is done by causing the double-arm lever *l*, which is fulcrumed at *f*, Fig. 93, and operated by an eccentric rod attached at *e*, and which ordinarily opens the exhaust valve by lifting the upper rolling lever *l*, to bear with

its right-hand extension and roller *r* against the tongue *k*, which is interposed by throwing the starting lever *s* in position. Thus the opposite phase of the eccentric's motion is utilized for reopening the exhaust. The pivoted tongue *k* is automatically thrown out of operation by means of spring *t* as soon as the starting lever *s* is thrown back to its rest position.

Figure 94 gives a longitudinal section and side view of the starting valve *m* and of the gear serving to operate it. The hand lever *a* when turned 90 deg. slides the cam *c* into working relation with the valve stem *b*, the cam being keyed on the shaft *d*

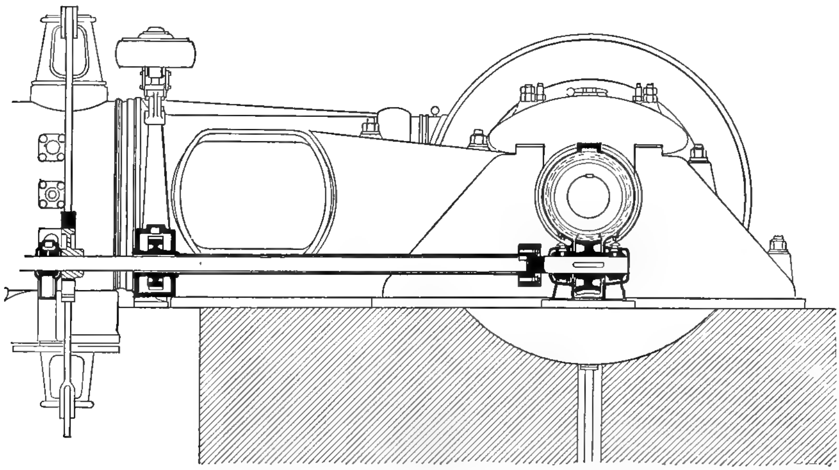


Fig. 92. — Driving Governor by Separate Tube Concentric to the Cam Shaft.

which is actuated by the eccentric rod by means of a roller *g* bearing against the cam plate *h*. At the same time the electric connection leading to the igniter is short-circuited, so that no premature ignition can occur. After the engine has been run up to its normal speed by means of the compressed air from the tank, the two hand levers previously referred to are thrown back into their normal position in reverse succession so that the engine begins to work on the four-cycle.

The Water Pump

In the Union engine which was exhibited at Liège the oscillating movement of the telescopic pipe which leads from the water

main to the swinging back crosshead has been utilized to pump the cooling water through the piston and rod. Fig. 95 is a cross section through this arrangement; p is the pump plunger, which is hollow and serves as an equalizing chamber. The water enters through the hollow shaft S, suction valve v_1 and pressure

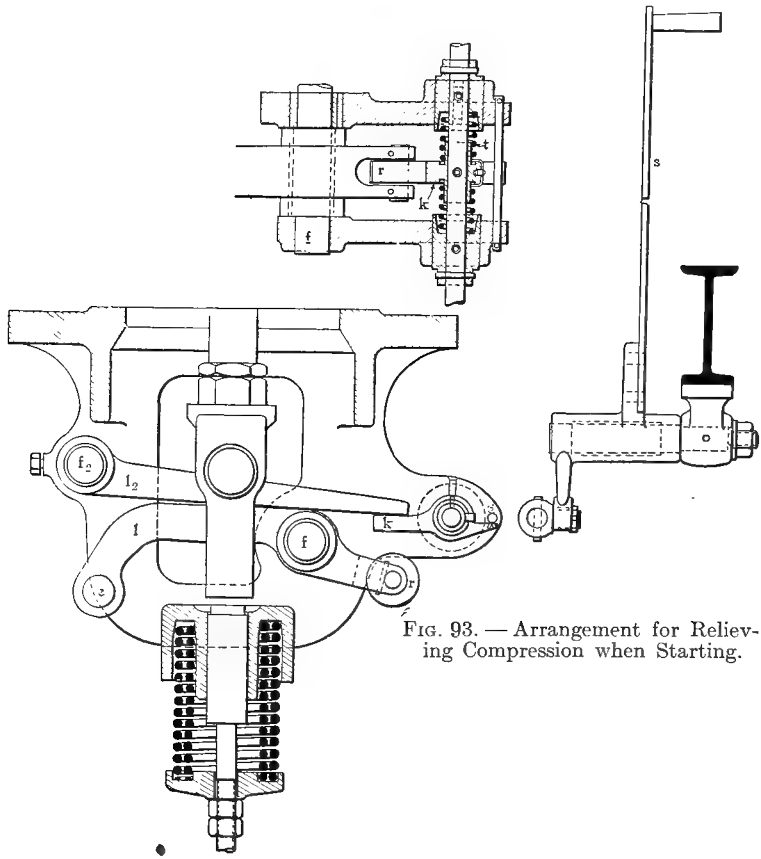


FIG. 93. — Arrangement for Relieving Compression when Starting.

valve v_2, the latter being screwed into the end of the plunger. The water proceeds in the inner concentric tube t in the direction indicated by the arrow up to another hollow shaft s, which is fulcrumed to the guide shoe g; thence it passes into the piston, which was shown in Fig. 77.

A channel c which extends along the guide bed serves to dis-

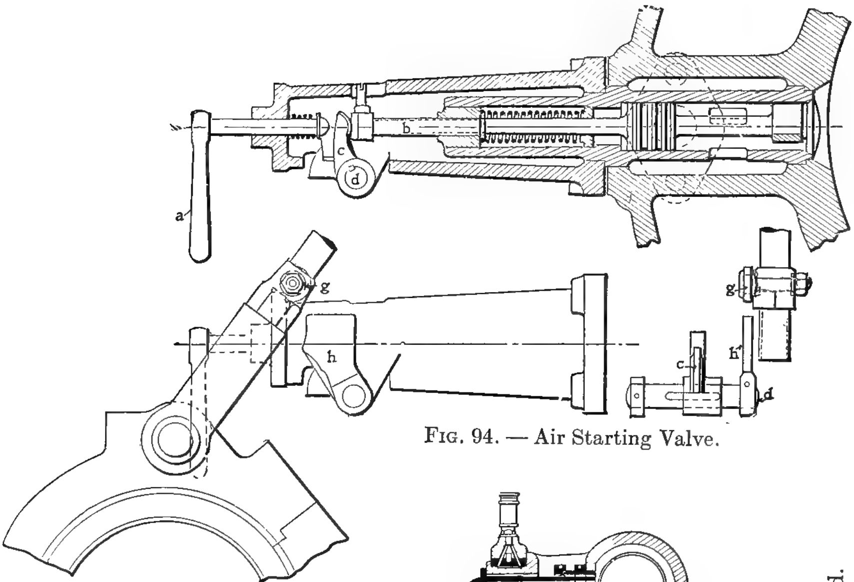


FIG. 94. — Air Starting Valve.

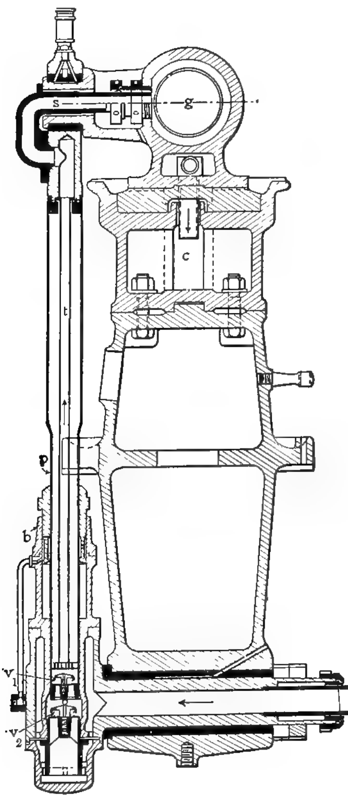


FIG. 95. — Pumps for Supplying Cooling Water to Piston and Rod.

charge the hot water coming from the piston. The arrangement for lubricating the swinging joints and the stuffing box *b* through which the plunger *p* enters the pump casing is also shown in the drawing. The various parts of the engine have each their individual cooling system, the water being taken from a common pipe which can be cut off from the main and from each individual branch pipe by means of valves. The various outlets for the water are distributed in a similar manner and discharge all into one common trough or pipe at the back of the engine, whence the water flows to a cooling and cleaning plant, later to be pumped back to the engine and used over again. The piping for water, oil and exhaust as well as the arrangements for starting may be studied from the figures showing a longitudinal section, a plan view and two cross sections of the double-acting engine.

In sizes above 300 h.p. the Reichenbach engine is built in the double-acting tandem form, and from 1600 h.p. up to the largest size, 4000 h.p., it is built as a twin tandem engine.

VII

THE KÖRTING DOUBLE-ACTING TWO-CYCLE ENGINE

There is no large gas engine on the European and American markets which has been the subject of livelier discussion, of keener misapprehension, and of wilder technical speculations than the Körting engine; none that has worked so successfully under similar adverse conditions of practice, operated by an untrained and ignorant staff of attendants, running on half-cleaned gas loaded with dust, dirt, moisture, and other impurities, and yet doing continuous and satisfactory service where no other prime mover would have lasted. It is only fair to the designers and builders of the Körting engine to open a discussion of its working principles and constructive details with this statement, since the largest gas-power plant in this country (owned by the Lackawanna Steel Works at Buffalo) is equipped with Körting engines aggregating some 40,000 h.p., and since rumors of the failure of this plant have done a great deal to undermine the confidence of the purchasing public in this type of prime mover. The real cause of the various troubles encountered at the Lackawanna plant is primarily the deficiency of the gas-cleaning apparatus employed, and this must first be remedied before any sweeping statement or criticism of the engines themselves can be made. In a recent test made on the Lackawanna plant by Dr. Lucke, of Columbia University, the interesting fact was revealed that in a run of 1 month 10 lb. of dirt accumulated on the inlet valve of one of these engines, and it remains yet to be shown what four-cycle, or what steam engine, would run with a similarly dirty working medium for the same length of time to the satisfaction of the owners.

There is no engine built that shows better speed control, affords more correct proportioning of the two charge constituents, or is easier to start under load than the Körting; none that requires for the same regularity of running less floor space per

unit capacity; none that is more compact and rigid in design and construction. But, of course, there are also some drawbacks attached to the system as it stands now, which must be eliminated in order to secure all of the advantages inherent in the type, and to establish the superiority of the double-acting two-cycle over the double-acting four-cycle tandem engine, which is yet only a matter of theoretical argument.

Prospects and Limitations of Working Cycle

The action of the Körting engine has often been compared to that of a modern horizontal condensing steam engine, because there are two power strokes in the cylinder per revolution of the shaft, and pumps participate in the working process. This similarity is a merely incidental and external one, since the admission, compression, expansion, and expulsion of the working medium are absolutely different, and no conclusions can be drawn from it as to the applicability of the two types for various uses. Moreover, the Körting engine is an entirely original type of gas-engine design which, by the improvement of constructive details, can be brought to higher mechanical and thermal excellence, but with all inventive ingenuity can never find more than a strictly limited field of usefulness. The Körting engine, as well as all other makes of large two-cycle machines, charging with an open exhaust, is restricted to low speeds, say from 80 to 100 r.p.m., since the time available for the escaping of the old and the introduction of the new charge is concentrated in an interval of a few hundredths of a second. Further, such engines are restricted to just one special method of regulation, because when charging with an open exhaust the only possible way of reducing capacity is to decrease the ratio of combustibles to air and residual gases, while the maximum output is also a constant amount, rigidly fixed by the total cylinder volume at atmospheric pressure. Therefore, overload capacity in the meaning as applied to steam-engine practice is not possessed by the ordinary two-cycle engine.

As compared with four-cycle engines, the capacity of engines of the two-cycle type is, theoretically, higher, owing to the more or less complete scavenging of the clearance space from residual gases, and to the difference in admission pressure of the respective working media — the one being sucked into the

working cylinder by the main piston and the other being delivered at a pressure of from 8 to 10 lb. per square inch. In practice the mean indicated pressure in the working cylinder is usually lower than the corresponding item in large four-cycle engines. Since, in order to avoid gas losses through the exhaust port, there must be a zone of air interposed between the new charge and the exhaust port, the maximum capacity of these engines corresponds to the total cylinder volume filled with combustible mixture at atmospheric pressure minus space occupied by the layer of air. To avoid pressure and friction losses the scavenging and charging media must enter the working cylinder under constant and low pressure compatible with the thorough expulsion of the burnt gases and proper valve area. Real overloading, as with steam engines and turbines, is not possible in two-cycle gas engines unless the working medium, or rather the two constituents of the charge, be compressed separately up to the economic pressure limit, and fuel and air are admitted at the beginning of the power stroke in correct proportions and at a rate corresponding to the piston speed to mix and ignite, creating continuous combustion up to a certain point of the stroke which corresponds to the cutting off of the admission by the governor of the engine, according to the load. It is well to be quite clear about the limitations of the present type of two-cycle engines before going further into their discussion.

Two pumps, one for air and the other for gas, deliver the two constituents of the charge into the cylinder. They are both driven from the same rod, the crank of which is set at an angle of 110 deg. in advance of that of the main shaft. If both pumps delivered through the whole of their common pressure stroke, the proportion of gas to air would be invariably the same and would correspond to the ratio of the respective pump piston areas. For regulation purposes it is required that the quantity of gas delivered per power stroke vary somewhat in proportion to the load, while the quantity of air remains the same for all conditions. Referring back to the discussion of the Oechelhäuser engine, it was shown that the object of the scavenging air in two-cycle engines is primarily to interpose a stratum of neutral air between the outflowing hot gases from the preceding combustion and the new power charge, which enters the cylinder immediately behind the scavenging air. Consequently it is necessary that the

air pump should begin its delivery shortly after the opening of the exhaust ports, that is, after atmospheric equilibrium has been established in the power cylinder, while the gas pump must begin to deliver somewhat later, at a point corresponding to the momentary load.

Figure 96 shows graphically the relative positions of the main and pump cranks, which are identical for both ends of the cylinder. When the main crank has still to complete a travel corresponding to say 40 deg. crank angle before reaching the dead-center position, the piston begins to uncover the exhaust ports. At this

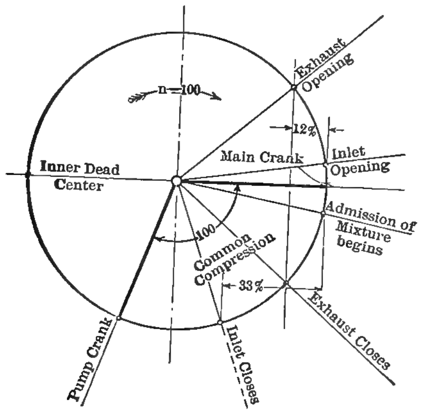


FIG. 96. — Crank Diagram of Körting Double-Acting Two-Cycle Engine.

moment the internal pressure is still high, from 2 to 3 atmospheres or 28 to 42 lb. per square inch, consequently the gas rushes through the exhaust slots at a very high velocity — from 200 to 400 m. per second. When the crank is only 20 deg. distant from the dead center, the internal pressure has diminished nearly to the atmospheric, and shortly after this point, the inlet valve is opened to allow air from the air pump at a pressure of about 8 or 9 lb. per square inch to enter the cylinder and sweep out the residual burnt gases, or, in any case, to reduce their temperature so that when the gas pump begins to deliver (the air pump continuing its action) the explosive mixture of gas and air is not prematurely ignited by contact with the old charge. The returning piston closing the exhaust ports, and the admission being still open, there follows a period of common compression by both the pump

and the main pistons, until the inlet valve closes, which is done after the main piston has completed about 33 per cent. of its return travel. According to Körting's earlier views, the cylinder contents at this point are separated into three layers, consisting of burnt gases, air, and combustible mixture, their respective location and quantity depending on the load. Now it is quite easy to imagine that immediately after the closure of the inlet valve there exists for an infinitely short time an actual condition of stratification such as that claimed, but it is not at all likely that this stratification is maintained during the ensuing compression stroke. Though the time for diffusion and influx of heat is

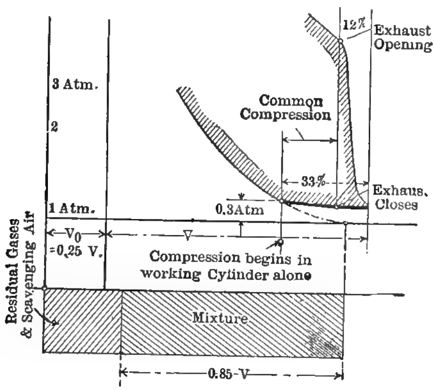


FIG. 97. — Combined Pressure and Volume Diagram.

very short, yet the whole mass of gases is by the returning piston compressed to about one-fifth of its original volume, and the only legitimate conclusion one can draw is that in the immediate vicinity of the inlet valve the mixture is likely to be richer than it is near the piston. All other assumptions are mere guess-work, but for the efficiency and reliability of the combustion process it is sufficient that a rich mixture be provided in the immediate vicinity of the igniter, so that inflammation is promptly produced and rapidly propagated throughout the mass of gas.

Figure 97 gives the combined pressure and volume diagrams, showing the sudden drop of pressure at the moment of port opening, which occurs at a distance of 12 per cent. of the stroke before the piston reaches the dead center. During this combined period of 24 per cent. of the stroke the three processes of exhausting

the burnt gases, introducing the scavenging air, and admitting the new charge have to be performed. For, contrary to the understanding of many, the period elapsing between the closing of the exhaust ports — which with invariable length of piston rod occurs at the same point as the opening — and the closing of the inlet valve is not available for the prolongation of the charging process, as will be shown presently. But this interval is an unavoidable feature of the action of the inlet valve and gear mechanism, the masses of which cannot be accelerated and retarded to their fullest extent within the short time of a few hundredths of a second while the exhaust is open, without risking fracture of

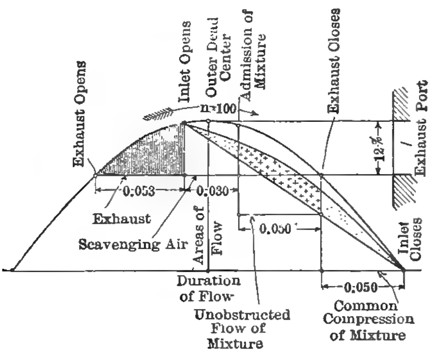


FIG. 98. — Valve and Port Opening Diagram.

the gear. Fig. 98 is a valve and port-opening diagram, showing the time relations between the port opening and valve lift and the discharge of burnt gases; also the introduction of scavenging air and new mixture and the compression of the charge up to the point of closure of the inlet valve. It is self-explanatory.

In commenting on these diagrams, presented by Professor Riedler, of Charlottenburg, Herr Carl Weidman, Doctor of Engineering at the Technische Hochschule of Aix-la-Chapelle, Germany, gives an interesting contribution to the very important problem which naturally arises when studying the charging process of two-cycle engines which employ external pumps, raising the question whether it is not possible in order to avoid losses of mixture through the exhaust and create overload capacity, to continue the admission of a new charge after the ports have been closed by the piston. Figs. 97 and 99 give an answer

to this question as far as the Körting engine is concerned. If admission of the charge into the working cylinder took place after the exhaust were closed, then the rate of compression effected by both the main piston and the pumping piston would have to be higher than if the compression were taking place in the power cylinder alone and when the inlet is closed. The heavy curve Fig. 97 would therefore have to turn upward considerably from the direction shown; in other words, the curve ascends actually much flatter than would either the curve of common compression or single compression, which means that during the period of combined action of both the main and the pumping pistons, part of the power charge is forced back from the working cylinder into the overflow channels connecting with the pumps.

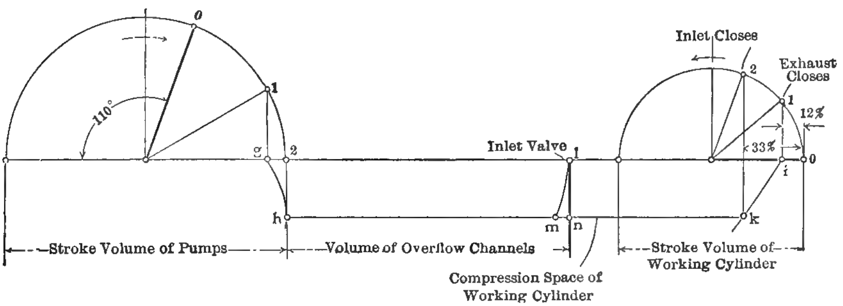


FIG. 99. — Diagram Showing Action of Pumps.

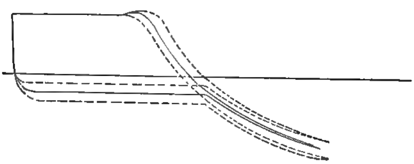
This becomes even more evident from the volume diagram, Fig. 99, where the combined stroke volume of the two pumps has been drawn together with the volume of the overflow channels, the clearance space of the working cylinder and the stroke volume of the latter. The ratio between the stroke volumes of the main cylinder and the pumping cylinder has been assumed as 1 to 1.5, which corresponds to actual conditions in the Körting engine. The volume of the overflow channels was taken as equal to that of the stroke volumes of the pumps, and the clearance space of the working cylinder is 25 per cent. of its stroke volume. The corresponding position of the main and pump cranks, which are set at an angle of 110 deg., is indicated by identical numbers. The curve *g*-*h* represents that portion of the pump piston travel which is described during the period of common compression,

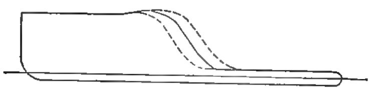
while the curve *i-k* represents the corresponding portion of the travel of the working piston. The total volume inclosed between these three pistons has, therefore, during the period of common compression been reduced in a ratio expressed by the difference between the lines *g-h* and *h-k*. As the increase of pressure within the whole mass proceeds at a uniform rate, and as slight differences in the value of the compression exponent existing at different points of the mass can for moderate pressure changes be neglected, it is obvious that the mutual relations of the individual portions of the volume remain constant during the whole of the charge. Therefore the equation $g—1 : 1 — i : : h—m : m—k$ can be adopted for constructing point *m*, which means that the molecules of the mixture which at the beginning of common compression were located near the point 1, that is, near the inlet valve, have been shifted at the end of such compression (when the inlet closes) to the point *m*. Hence one finds that during the period of common compression a quantity of mixture represented by volume line *m-n* is pressed back from the working cylinder to the overflow channels in the immediate vicinity of the inlet valves. Therefore, the admission of charge into the working cylinder of the Körting engine as at present designed cannot be continued beyond the closure of the exhaust port, and no overload capacity over what is rigidly determined by the total atmospheric cylinder volume can be obtained. To avoid the expulsion of part of the power charge and consequent loss in capacity by fluid friction and pump work, the inlet must close with the exhaust. But, as already stated, the difficulty of opening and closing the large inlet valve to its fullest extent makes this impossible.

The process of scavenging and charging is a combined and fixed process, determined and carried out by the air and gas pumps. Being mounted on the same rod, the two pump pistons begin their downward travel at the same moment, and the proportion of air to gas is entirely dependent on the respective piston areas, so long as both pumps are delivering simultaneously. But, depending on the quality of gas used, the delivery of the gas pump begins earlier or later, usually after completing 50 per cent. of its pressure stroke, during which time the air pump is at work. Now during this 50 per cent., a certain portion, depending on the load, is returned to the suction side of the pump by means of an overflow device controlled by the governor. In the earlier forms

of pump, using piston valves, a throttle between the suction and delivery side was operated from the governor, and the closing of the suction took place after the piston had traveled 50 per cent. of its stroke. During the succeeding pressure stroke the delivery remained closed, and the gas drawn in during the preceding stroke re-entered the suction pipe. During the second half of the pressure stroke, the delivery was opened and from that time the two pumps delivered together gas and air at the same speed per unit of time, so that the composition of the mixture remained the same.

Figure 100 shows the action of a gas pump working in the manner described. Fig. 101 shows an indicator card from a gas pump having an overflow from the pressure to the suction side, which is regulated by a Rider slide valve controlled from the





FIGS. 100, 101. — Indicator Cards from Gas Pumps, Working with Different Regulation.

engine governor and closing at an earlier or later time, according to the load. The constructive details will be shown later. Compared to throttle governing the negative work against the vacuum is avoided in the latter construction and low pressure during the delivery stroke attained; moreover, the governor, the regulating action of which ought to be as near the period of energy development as possible, exercises its influence during the delivery stroke and not before, so that the effect of the governor's motion is felt one stroke earlier than with throttle regulation. Of course in four-cycle engines, the governor acts even earlier, namely, during the suction stroke, but then there is in two-cycle engines of the scavenging type a large volume of charge contained in the overflow channels which escapes regulation, so that there is really little difference between the two- and four-cycle engines as regards promptness of regulating effect.

In the overflow, the separation of the two constituents, air or gas, is maintained up to the immediate vicinity of the inlet valve,

the mixing taking place at the entrance of the cylinder only, and when the inlet is open. But this valve is closed at the commencement of the delivery stroke of the piston of the air pump. It opens only after the pump piston has performed about one-half of its stroke. During this time air accumulates in the passage and, in consequence of its pressure, passes into the gas passage, forcing back the gas, as the gas pump is not at this time delivering. Therefore, pure air only enters the cylinder from the moment of the opening of the inlet valve, until the gas pump begins to deliver, and this air serves to provide the theoretical neutral zone between the burnt gas and the new mixture. In fact, however, owing to the retarding of the inlet valve closing, a portion of the mixture is forced back into the overflow channel. This mixture must enter the air passage as well as the gas passage,

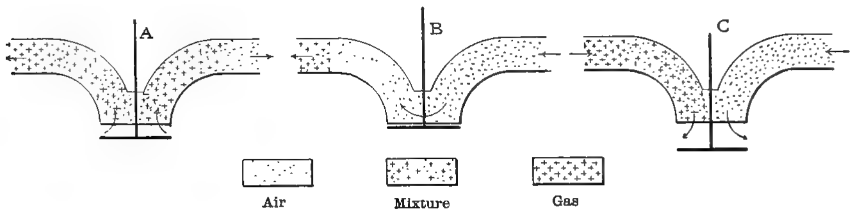


FIG. 102. — Diagram Showing Distribution of Gases in the Neighborhood of Inlet Valve.

both being subjected to equal pressure, so when the air pump begins its next delivery stroke, this mixture instead of gas is passed back into the gas channel. Therefore, for a fraction of a second, an explosive mixture under pressure is stored in the overflow between the air pump, gas pump, and working cylinder. Further, when the inlet valve opens, the mixture and air are delivered behind the scavenging air into the power cylinder instead of the correct proportion of gas and air. The capacity of the engine is therefore reduced, and the correct composition of the charge endangered, and this is worse the longer the time interval that elapses during the closing of the exhaust and that of the inlet. So this difference must be reduced to a minimum.

Figure 102 shows diagrammatically the flow of gases in the neighborhood of the inlet valve. Of course, there is no fixed limit between the different zones of gas, mixture, and air, such as shown on the diagram, because diffusion takes place, though

owing to the small contact area this is inconsiderable. In position A the exhaust has closed, while the inlet is still open. Part of the mixture of gas and air previously introduced is, therefore, pressed back by the returning piston into both overflow channels against the action of the two pump pistons, which reach the end of the delivery stroke when the inlet valve is closed. Conditions remain unchanged until, in position B, the air pump begins its delivery stroke (the gas pump running idle), pressing the mixture over into the gas channel. Shortly after the opening of the exhaust ports by the main piston, the inlet valve is opened, allowing the air first to enter the engine cylinder and either drive out residual gases or form a neutral zone between these gases and the incoming new charge. The gas pump begins its delivery after 50 per cent. of the air pump's stroke is completed, and at this point the condition C is established, air entering together with the remainder of the former mixture. It is only after this mixture is introduced that regular delivery of gas and air in correct proportions takes place. Strictly speaking there are, then, four layers contained in the cylinder, if stratification be assumed for the moment, namely, residual burnt gases, scavenging air, mixture of gas and air with scavenging air, and a mixture of gas and air in correct proportions. However that may be, the fact is that the calorific value of the charge increases toward the inlet valve so that near the igniter a rich mixture must always be formed; this is all that is necessary. Ignition is provoked about 18 deg. before the crank reaches the dead center. The process at the other end of the double-acting cylinder is, of course, exactly the same, only the phases change about 180 deg. The mechanical details of the pumps and other parts will be discussed later.

It can be seen from the foregoing considerations that piston pumps rigidly connected to and operated from the engine can be used for one special kind of gas only, and that their invariable volumetric capacity and size is unfavorable for the employment of gases of extremely varying calorific value, such as coke-oven gases. Furthermore, an engine that is designed for using coke-oven gas cannot run on blast-furnace gas, because the calorific value per unit volume is quite different. On the other hand, a blast-furnace engine, in order to run on coke-oven gas, would either have to throttle the gas intake or dilute the gas with air until its calorific value per unit volume was equal to that of

blast-furnace gas. The first way is wasteful, the second dangerous, so the only solution is to equip each engine with pumps of volumetric capacity appropriate for the heat value of the special gas used. Altogether, the action of the pumps guarantees, with the exception noted above, the delivery of a constant quantity of scavenging air at constant pressure under all loads, and of a fairly well regulated and well diffused mixture of gas and air without using any special inlet-valve governing devices; also, an excellent speed regulation at speeds of from 100 down to 30 r.p.m and of easy starting under load in the shortest time. The latter features are not possessed by the ordinary four-cycle engine.

Regulation

It was said that all two-cycle engines which employ exhaust slots for the expulsion of the burnt gases, and which admit the new charge while the exhaust outlet is still open, must adopt the system of pure quality regulation, which is the second oldest of all governing processes, the oldest being the hit-and-miss method. Its advantages are that compression remains invariably the same for all loads, as the cylinder is always completely filled with mixture, air, and residual gases of atmospheric pressure and represents a constant amount under all conditions; and that the pressure change at or before the dead-center position of the crank occurs regularly and without knocking of the gear. Furthermore, the inlet-valve springs have only to be strong enough to accelerate the mass of the valve when closing, but need not resist any internal suction effect, like those of an engine working with quantity regulation. The disadvantages of this method when employed in four-cycle engines are equally pronounced. The weakening of the mixture with decreasing load soon establishes a condition in which the lean mixture inflames only sluggishly, and even with advanced ignition after-burning takes place during the whole of the following expansion stroke, so that a considerable part of the heat developed escapes through the exhaust without being utilized. When the gas influx is still further reduced the lean mixture is no longer ignitable and leaves the cylinder unburned, often being the cause of back explosions in the exhaust pipe or the muffler. Of course the phase of load at which these well-known phenomena occur depends entirely on the thermal

characteristics of the special gas used, and will be reached earlier or later according to the lower or higher inflammability of the gas. But, as a rule, the reduction of gas influx cannot be carried farther than down to half load, and with some gases it has to cease even earlier in order to avoid heavy losses of gas and back explosions. Moreover, it is obvious that below half load the governor must lose control of the engine, since the charges are no longer regularly ignited.

The disadvantages of quality regulation just cited are less pronounced in the two-cycle engine than in the four-cycle type, being neutralized or equalized to a certain extent by conditions which tend to improve the thermal efficiency of the process. It is known that heat losses in gas engines are due, on the one hand, to imperfect combustion, owing to either an insufficient quantity of oxygen being present to support combustion, or on account of the dilution of the power charge through inert gases, or in consequence of an imperfect mixture of gas and air; on the other hand, to the conduction of heat to such inert gases and to the walls surrounding the combustion chamber. The difference in the efficiency of this regulating process between two-cycle and four-cycle engines is primarily founded on the two first-mentioned phenomena, since residual burnt gases consisting of carbon dioxide, steam, and nitrogen are apt to retard flame propagation considerably, and when present in excessive quantities will arrest the inflammability of the charge altogether.

In all cases the range of explosiveness is smaller with diluted mixtures than with pure ones, and decreases when the temperature increases. Therefore, the expulsion of the residual burnt gases from the cylinder of two-cycle engines is certainly an advantage which the former type possesses over the latter. At full load the residual burnt gases of a four-cycle engine represent about one-fifth of the stroke volume of the engine. Considering that the volumetric efficiency, or rather the suction capacity of this type, is about 0.85 of the stroke volume, the dead space occupied by the hot gases is about 25 per cent. of the total volume of the power charge aspirated. Leaving aside the reduction of the charge influx through heat transference from the residual hot gases, it is certain that at lower loads conditions get worse, as the burnt gases in the cylinder represent an almost constant amount compared to the quantity of gas admitted, or

to the quantity of mixture proper, or to the calorific value of the charge, which decreases with decreasing load. Unfortunately these gases are, in four-cycle engines using quality regulation, located in the immediate vicinity of the igniter, and what is worse, the time available for diffusion with the aspirated new charge extends over the whole length of two strokes.

The designers of the Premier engine in England have tried to eliminate this deficiency of the four-cycle type by using an extra pump for delivering scavenging air at the end of each power stroke in order to clear the combustion chamber of burnt gases. This engine shows a gain of 13 per cent. in heat units per indicated horse-power over what is obtained without scavenging. Of course, the engine capacity is also increased. Notwithstanding all that, the writer does not believe that the all-round economy, which is the product of mechanical and thermal efficiency of such a combination, is higher than that of an ordinary well-designed four-cycle engine, since the scavenging pump is an additional power-, material-, and labor-consuming element, outweighing the thermal gain by a mechanical loss. But in any case it gives evidence of the fact that where scavenging is a natural feature of the process as in two-cycle engines, it has a marked favorable effect on combustion efficiency, capacity, and regulation at the higher loads.

It is not advisable, therefore, to extend quality regulation below half load. A vastly more economical practice would be to cut out the power strokes altogether by arresting the admission of gas to the cylinder, so that only air is admitted, compressed, heated, and expanded, instead of consuming and exhausting unburnt gases. With double-acting two-cycle engines the effect of this manner of governing on the coefficient or regulation is, of course, less felt than with the four-cycle type, provided that down to say 60 per cent. of the maximum load quality governing is employed and from this point down to no load, hit-and-miss regulation. With Körting engines as built at present this combination system is not applicable.

Two-cycle versus Four-cycle

The double-acting two-cycle gas engine as devised by Körting aims toward the realization of the same mechanical excellence, reliability, simplicity, and accessibility that have actually been

attained in the perfection of large steam engines after years of continuous and vigorous development. But these desirable features are to be attained together with an accompanying thermal excellence far superior to anything ever performed by a steam prime mover, from 9000 to 10,000 B.t.u. per brake horse-power-hour being the upper limit rigidly drawn for the consumption of heat. All this is to be done at the lowest possible cost of manufacture, in order that the thermal gain or the reduced expenditure for fuel may not be outweighed by the increased interest on the initial cost of equipment, thereby making the value of the new machine commercially problematical.

When commenting on the constructive details or on the economic performance of any engineering innovation one is invariably confronted by the necessity of referring the particular application to some standard of comparison, else the discussion will resolve into a mere perfunctory description which is without real value to the discriminating student, especially when he is concerned with the investigation of a subject on which little accurate and scientific knowledge is available. The result of such comparison will depend largely on the judicious selection of the standard application referred to; in other words, unless the standard is correct the comparative estimate of two things is merely of a speculative nature.

In the particular case at hand the only true measure for estimating the merits of the Körting engine is by comparing it with the double-acting four-cycle tandem engine. As far as the general constructive arrangements of parts is concerned, the former type resembles in its latest design, even more closely than the latter, the modern large horizontal steam engine, which has served as a model to both. Central distribution, transmission and absorption of the variable forces by a rigid frame, central flange connection between the latter and the cylinder and tail end, moderate hight and weight but great stiffness, and easy accessibility, allowing of quick dismantling of parts, all these are characteristics common to both types.

A difference exists in the number of working parts, the tandem engine having two working cylinders with four inlet, four mixing, and four exhaust valves, and their gear, instead of one working cylinder with two inlet valves and exhaust ports in the Körting type. Instead of the second cylinder the latter has a pump for the

delivery of gas and air, which is usually divided into two cylinders with their respective inlet and overflow valves and gear. Everything considered, the Körting engine cannot claim greater simplicity or a less number of working parts which would result in lower cost of manufacture, but it can claim that the pumps, which take the place of the second cylinder of a tandem engine, are subjected to lower stresses and wear than is the latter, their internal pressures ranging from 3 to 8 lb. per square inch, against 350 to 420 lb. in the cylinder of a four-cycle tandem engine. Since we cannot speak of thermal superiority of the two-cycle over the four-cycle type — though incidentally the highest indicated efficiency so far recorded of a large gas engine was attained with an engine of the Borsig-Oechelhäuser type — the questions of mechanical superiority, greater reliability and simplicity of working parts, smaller floor space and lower cost of manufacture, will ultimately decide the question whether the one system or the other is to be adopted for general power work.

For blowing service, rolling-mill drive, pumping, and the propulsion of vessels, which is the latest application of gas power, the two-cycle engine possesses the undeniable advantages of perfect speed regulation and quick starting under load, factors which are indeed of no mean order of magnitude. For blowing service, the combination in the four-cycle type of three cylinders (two tandem and one blowing) becomes abnormally long, at the cost of stiffness, especially if only the main frame is rigidly fastened to the foundation block in order to allow for longitudinal expansion and contraction. For marine work, and for all purposes where small floor space is desirable, as in competition with steam turbines, the development of a large vertical type of engine is a necessity, and its feasibility must not be judged by the fact that the large vertical four-cycle engine formerly built by the Westinghouse Machine Company has been abandoned in favor of the horizontal type. The reasons for this policy are of an entirely different nature and do not militate in the least against the building of large vertical two-cycle engines for ship propulsion.

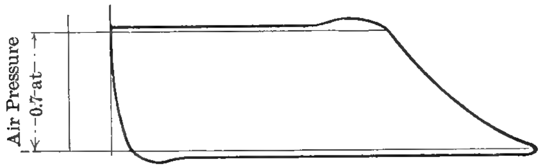
Adaptation to Blowing Service

For reasons which were fully set forth in an earlier part, the scavenging and charging process in engines of the Körting type

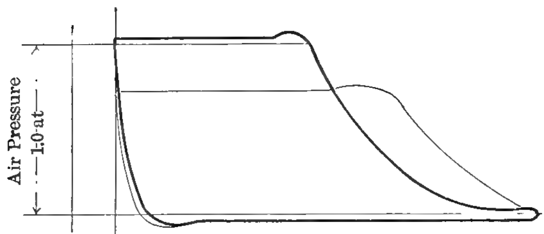
require two separate pumps, one for air and one for gas, unless the latter constituent is sucked in by the injecting action of the stream of air. Departure from this rule may be found in cases where air under pressure is available from some independent or outside source. Thus, in blowing service, air from the blowing cylinder may be delivered through an automatic reducing valve for scavenging and charging. This would eliminate the special air pump with its mechanical inefficiency, and would reduce the negative work and the cost of manufacture; but it would increase the fluid friction in the air passage and receiver.

Yet, considering all these points, I should recommend such practice wherever air under pressure is obtainable. Contrary to the opinion of Professor Riedler, expressed in the address previously referred to, I hold that the varying pressure of the blast, which is due to the varying condition of the furnace, and the lack of a device for exactly measuring and determining the quantity of air introduced into the gas-engine cylinder, do not present obstacles that cannot be overcome by proper design. Since the gas engine cannot, in the true sense of the word, be overloaded unless underrated by the manufacturer, and working at its normal or nominal capacity with a lower degree of efficiency than what is guaranteed and expected, the blowing cylinder must possess means which allow the pressure of the blast to be increased without increasing the duty on the engine, which is, of course, only feasible if the volumetric capacity of the blowing cylinder is reduced at the same time, and in corresponding ratio. This is done either by keeping the air-inlet valves of the blowing cylinder open for a portion of the return stroke, so that part of the air taken in during suction is discharged again, or by having special by-pass return valves, or by increasing the clearance space, so that the expansion of the compressed air contained therein to atmospheric pressure retards the suction effect of the blowing piston, thereby reducing the volume of air delivered. (See Fig. 103.) In order to attain the last-named effect, namely, increasing the air pressure from, say, 7 lb. to 14 lb. without increasing the duty on the engine but with reduced quantity of wind output, there is a series of dead spaces or chambers provided, usually three or four, which may be connected with the blowing cylinder through hand-operated valves, which are opened in succession. A special overflow serves to release the blowing cylinder for purposes of starting.

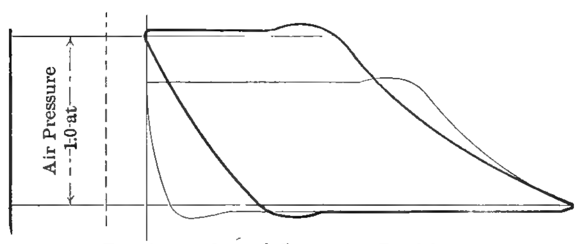
Then by increasing the speed of the blowing engine higher blast pressures may be attained with the expenditure of the same amount of indicated work, the process of energy transformation within the gas-engine cylinder being performed at a constant and high degree of efficiency. On the other hand,



Normal Diagram at 10 Lb. Blast Pressure



Regulation through By-pass Return



Regulation through Increasing Dead Space

FIG. 103.—Diagrams Showing Different Methods of Regulating Blowing Cylinders.

provisions are made for the attendant to be able to release the engine at once from the blowing load if obstructions in the blast furnace or elsewhere should require it.

Special requirements had to be met by gas engines when driving blowing engines for the operation of steel works, on account of the interruptions in the supply of the blast during the (Bes-

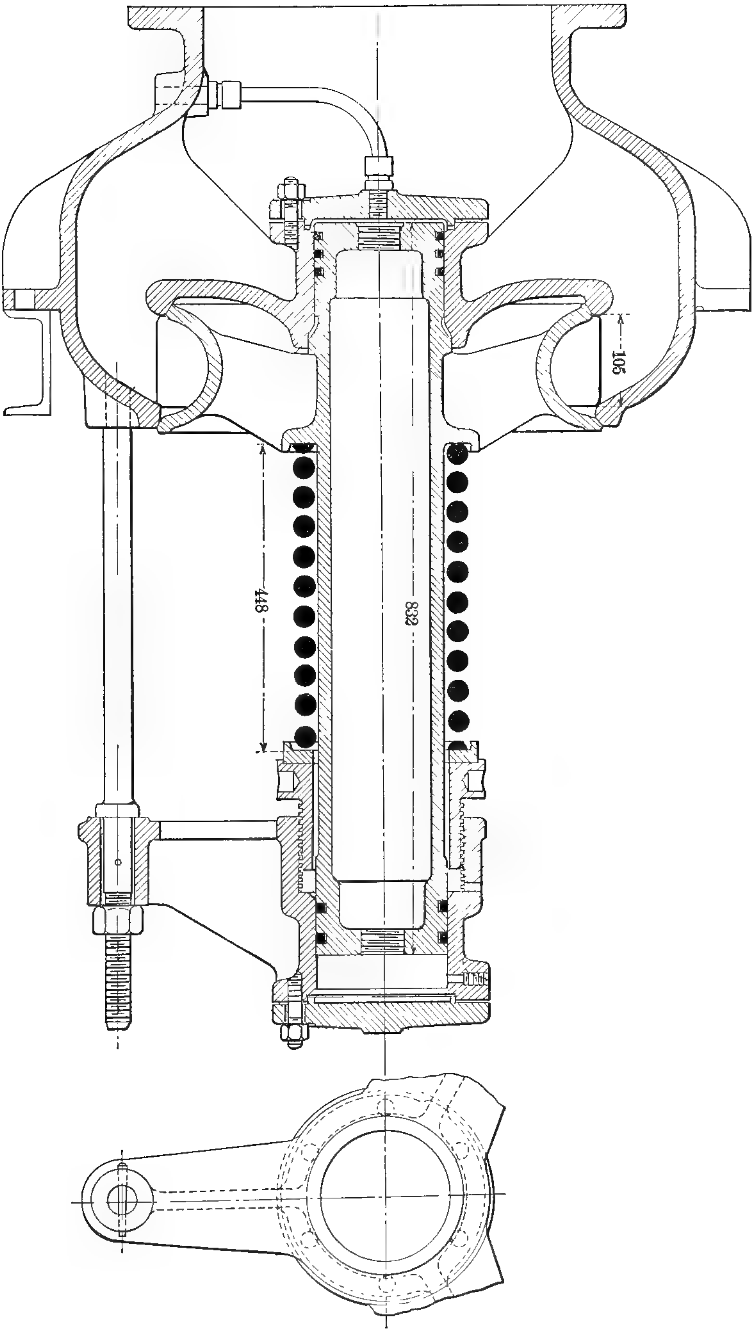


Fig. 104. — By-Pass Safety Valve for Blowing Engines (Nürnberg).

semer) smelting process. The *frequent* stopping and restarting of the prime mover is more difficult to perform with gas than with steam drive. With gas engines there is a great loss of compressed air unless they are started by an auxiliary electric motor, as is done in latest practice. Therefore the Nürnberg engineers have provided a by-pass for the blowing air, which can be quickly opened from the attendant's place by means of compressed air. So the gas engine continues its operation, while the blowing cylinder is released from pressure. This arrangement, which is shown in Fig. 104, has proved entirely practicable for the class of service for which it is intended.

Coming back to the particular application in hand: while the pressure of the blast will, therefore, vary according to the momentary condition of the furnace, the employment of a special automatic by-pass reducing valve makes it possible to keep the air receiver of the gas engine always filled with scavenging and charging air of almost constant pressure; and though the additional compression work consumed in the blowing cylinder must, of course, be credited against the total gain, this negative work may be kept within reasonable limits through by-passing the blowing air at an early part of the delivery stroke, so that the total saving effected by such combination is large enough to warrant its adoption wherever possible. But unfortunately this way of increasing all-round efficiency, which was proposed by G. H. Davin, is limited to one special field only, and one wherein the two-cycle engine is anyhow the first claimant for recognition as a prime mover on account of the ease with which a wide range of variable speeds can be attained, by simply regulating the gas admission to the pump.

Another method that I have proposed for delivering a large volume of scavenging and charging air under constant low pressure for use in two-cycle engines is to employ a high-speed centrifugal fan in such combination that the two cylinders of a double-acting, two-cycle twin engine are supplied, at the consecutive phases, from one central fan, thereby reducing the cost of manufacture of pumps and the negative work consumed to the lowest possible limit, while the reliability and simplicity are increased accordingly. The details and feasibility of this combination were discussed before and need not be here repeated. It may be added, however, that the employment of means sepa-

rate from the engine for delivering air and gas under variable pressures to the working cylinder has gained increased importance since the application of producer gas is coming more into the foreground, it being found that the rate of gasification must be varied not only in proportion to the engine or station load, but also in accordance with the condition of the fire, so that an automatic regulation of the draft through the fuel bed becomes essential. Obviously the two-cycle engine, even when using direct-connected piston pumps, allows the realization of this demand, with a higher degree of efficiency than does the four-cycle engine, since an increase in the suction effort of the gas pump does not directly affect the regular performance of the working process in the main cylinder.

Construction of Pumps

The gas and air pumps being the most important organism of the Körting engine, as far as the question of comparison with the tandem four-cycle type is concerned, it is advantageous to study their constructive features in detail. Fig. 105 is reproduced from Güldner's "Design and Construction of Internal-Combustion Engines," and shows an earlier design of pumps employed. Speed regulation is obtained by adjusting the quantity of gas introduced into the working cylinder to the momentary output, the effective delivery stroke of the piston of the gas pump being either shortened or increased. For this purpose there is contained inside the cylindrical slide valve *a* of the gas pump a special double-piston valve *d*, which governs the time of beginning of the overflow period. The main slide valves *a* and *b*, of the gas and air pumps respectively, are fastened to a common hollow rod *c*, which is connected to the first eccentric by means of links *c′ c′* and a rocker-arm *c.″* The auxiliary slide valve *d* of the gas pump is connected to the second eccentric by means of the rod *e* and rocker-arm *e*.

The air valve changes the connection of the air-pump cylinder with the suction and delivery passages near the ends of the piston strokes, but irrespective of the load, so that the same quantity of air is used under all conditions. The gas valve *a*, on the other hand, keeps the suction channels open until far into the pressure stroke, thus allowing at least half of the aspirated gas volume to flow back into the suction pipe. At maximum load the valves

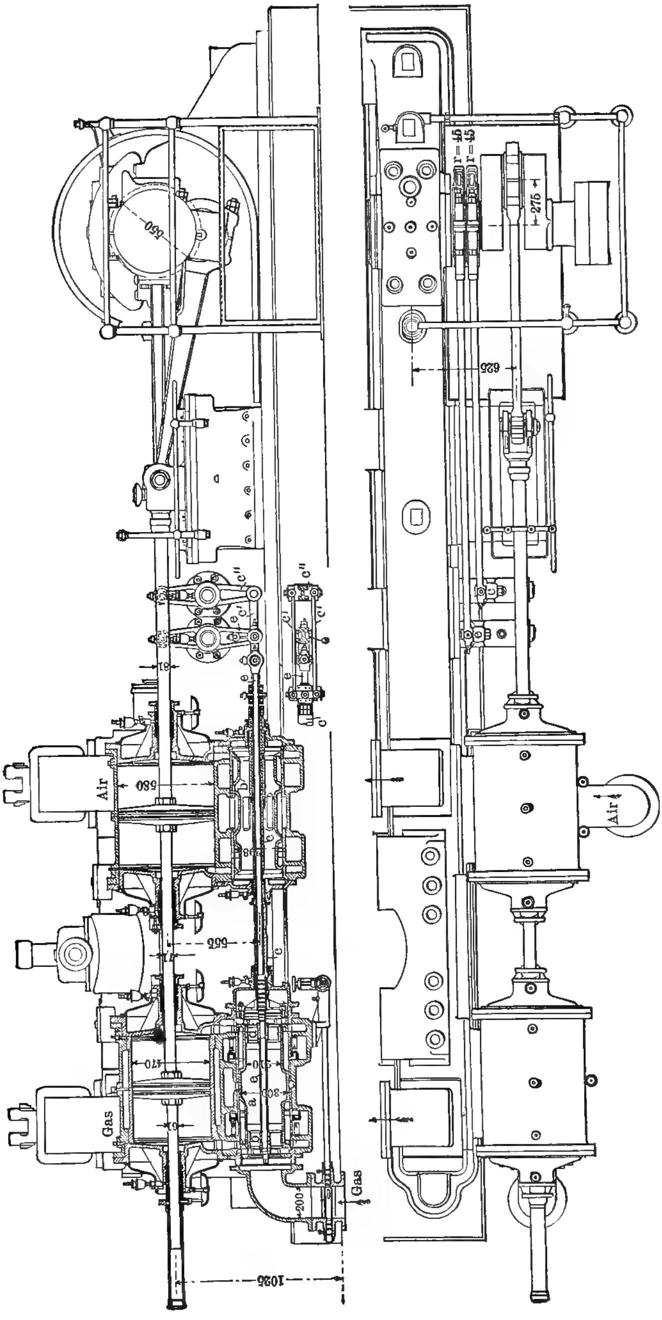


FIG. 105. — Earlier Construction of Körting Gas and Air Pumps and Their Regulation.

a and *d* close the suction passages after the completion of one-half of the pump stroke and immediately open the delivery passages to the working cylinder. At this moment the main crank, which lags by 110 deg. behind the pump crank, travels through the dead-center position. The auxiliary slide valve *d*, under the influence of the governor, makes this change take place later with decreasing load, thereby returning more gas into the suction passage and leaving less gas in the working cylinder. Another form of construction provides for the gas pump to re-aspirate more or less gas from the delivery channels leading to the main cylinder, thereby either reducing or increasing the quantity of fresh gas delivered. The final pressure in the pumps reaches 0.6 atmosphere or 8.53 lb. per square inch.

The action of the air and gas pumps, and especially the regulation of the latter, becomes even clearer upon inspection of Fig. 106, which shows the arrangement as built by the Gutehoffnungshütte, Oberhausen, Germany. Contrary to the construction first described, the respective piston slide valves *a* and *b* are actuated by two separate rods and rocker-arms *c d e* and *f g*, the effect being the same. Instead of two internal governing pistons there are here two external piston valves *h* and *i*, which are capable of rotary movement when influenced by the governor through the arm *k*, and also of a reciprocating motion parallel to the axis of rotation, when adjusted by hand lever *l*. Thus the slots connecting the delivery side of the gas pump to the suction side are opened more or less according to the kind or quality of the gas used and to the load on the engine. The small detail sketches in the upper part of Fig. 106 are the slide-valve diagrams of the air and gas pumps and the connection of the two eccentrics with the rocker-arms, rods, and piston valves.

Though the action of these pumps is extremely simple, their cost of manufacture is apt seriously to increase the total cost of engines of this type. Furthermore, the negative work consumed will, even with the best workmanship, run as high as 10 per cent. at full load. At lower loads and higher speeds the pump work runs even higher. Here we have one of the many cases which often occur in engineering practice showing how widely theoretical assumptions and beliefs may differ from practical performances. It seems obvious that in the four-cycle type, where the power cylinder serves as a pump for one-half of its working time,

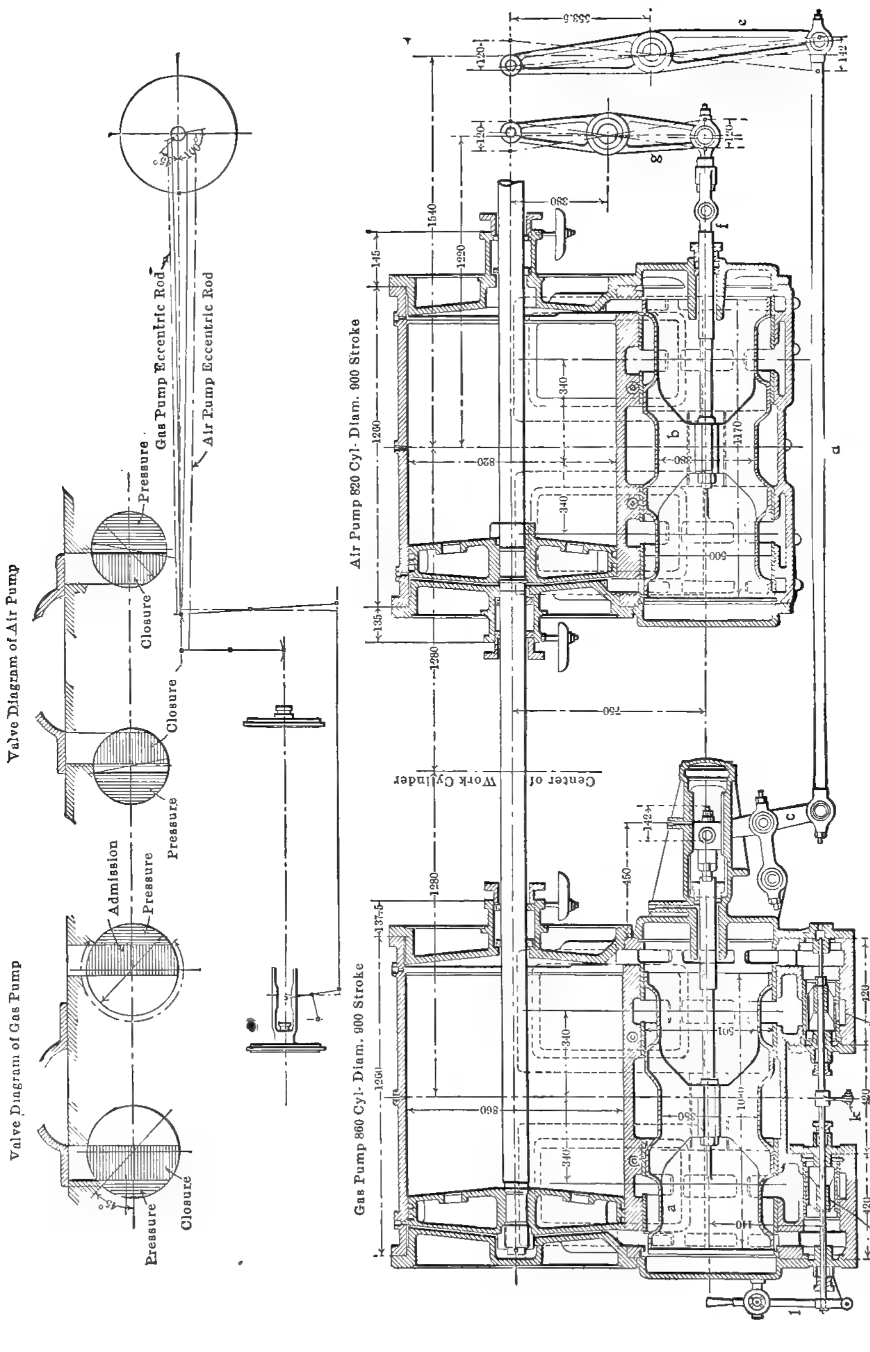


FIG. 106. — Gas and Air Pumps and Their Regulation, Built by the "Gutehoffnungshütte," Oberhausen, Germany.

its mechanical efficiency as compared to an independent pump must be low, because the valves are not designed as pump valves, and the piston rings are not light, but must be able to stand the much higher temperatures and pressures of the power strokes; moreover, the hot cylinder walls and the products of combustion contained in the clearance space must necessarily have a detrimental effect on the suction efficiency, and fluid friction must be higher. Yet notwithstanding all this, the fact remains that even with such well-designed pumps as those just described the negative work done by pumping is higher than the corresponding item of loss in the four-cycle engine. The friction resistance offered to air and gas in the overflow channels is not great enough to account for this difference. The only practical way to overcome these difficulties seems to resort to the central, centrifugal fan, which is specially designed for delivering air under constant low pressure, against low resistances, and at low cost.

Charging Process

Coming now to the feature of introducing the new charge into the power cylinder, in the Körting type of engine an inlet valve is required for introducing, first, scavenging air and then air and gas in correct proportions. Contrary to the practice in the Oechelhäuser engine, the introduction of the scavenging agent is not through slots symmetrically distributed around the circumference of the cylinder wall, but through an inlet valve located on top of the breech end of the cylinder. The flow of gases can therefore not proceed in form of a closed column, pushing the residual gases out before them into the exhaust, and forming layers of decreasing calorific value toward the piston head, but the process of expulsion and stratification will be more or less irregular, depending on the path of travel provided for the incoming stream of gas or air and on the pressure of the latter; also on the number of impulses per minute and on the time available for expelling the old charge and introducing the new.

The designers of the Körting engine have endeavored to reduce these uncontrollable factors to a minimum, by arranging a special baffle plate in the combustion chamber at a certain distance below the inlet valve, against which the incoming charge impinges in such manner that part of it proceeds straight through the

cylinder, while the other is deflected at right angles, producing, together with the first, a whirling motion which tends to fill the entire volume of the clearance space and cylinder with fresh medium, thereby driving out the burnt gases of the old charge more efficiently. The form and position of this baffle plate have been determined by careful experiments, and from the valuable research work which Herr Körting has conducted and the rich experience which he has acquired in the study of gaseous media, it can be taken for granted that the process of expulsion will, under certain fixed temperature and pressure conditions, follow the course just outlined, though of course there is no means of ascertaining, while the engine is in operation, whether these phenomena will occur in precisely the same fashion in the large and hot cylinder as they do in an experimental glass tube. Certain it is that at higher speeds the flow of gases will differ from that under normal conditions, and very likely it will take a course less favorable to perfect expulsion; this is one of the reasons why the number of revolutions per minute of the Körting engine cannot exceed certain limits. On the other hand, the expulsion of gases and the stratification of layers will be more perfect at the lower speeds where four-cycle engines would fail to operate.

The pressure of the scavenging agent and the power charge is determined by two limits. It must be low and, if possible, constant under all loads in order that the flow of gases may take the same course under all conditions, and that it may not pierce the remaining burnt gases but drive them out as completely and uniformly as is possible with the unsymmetrical introduction, so that the theoretically assumed stratification may actually occur; also, because the higher pre-compression of the new charge entails an additional loss through negative work consumed in the pumps and through fluid friction and heat transfer in the overflow, since charging with an open exhaust prevents the attainment of a pressure above the atmosphere at the beginning of the compression stroke. On the other hand, the pressure must not be too low, else the dimensions of the pumps, the overflow channels, and the inlet valve become abnormally large, the volume of charge which escapes regulation increases, and the short time available for scavenging and charging allows only incomplete filling of the cylinder so that a double-acting two-cycle engine would not have double the capacity of a double-acting four-cycle engine.

With the Körting engine as designed at present, about 75 per cent. of the total cylinder volume is at full load filled with fresh mixture of gas and air, the rest being taken up by scavenging air, or more likely, by a mixture of scavenging air and exhaust gases, located near the piston head. It is evident, therefore, that the pressure limits for the new air and power charge are very closely drawn by considerations which affect the mechanical efficiency and the thermal efficiency, as well as the capacity of the engine.

Obviously the expulsion of the charge would be done more efficiently and uniformly if the scavenging agent were introduced from the center of the cylinder head. This being impossible on

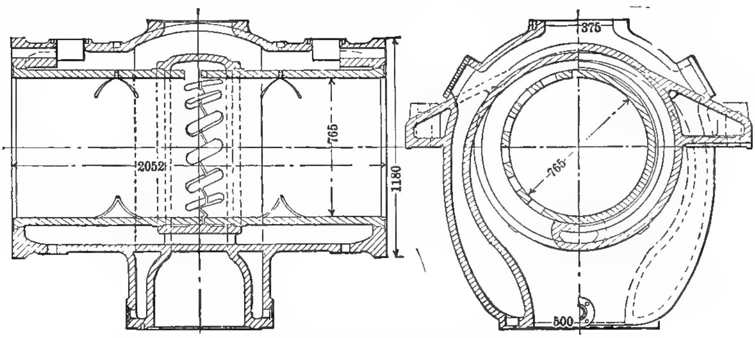


FIG. 107. — Cylinder of Double-Acting Two-Cycle Engine.

account of the piston rod and stuffing box occupying that part of a double-acting engine, the only chance for central introduction of the new charge consists either in providing several inlet valves symmetrically arranged around the center of the combustion space, or else in employing a ring valve surrounding the stuffing box. The first arrangement is, of course, very much more expensive than the ordinary construction, and the second is no less complex. As in many similar cases, practice will have to give the final answer as to the feasibility of an arrangement of this kind.

CYLINDER AND HEADS

Coming now to the discussion of the constructive features of the various parts, Fig. 107 shows a longitudinal and a cross section of a modern cylinder of the Körting engine, as built by the Gute-

hoffnungshütte, of Oberhausen, Germany. Contrary to former practice the cylinder barrel proper is not cast in one with the water jacket for reasons which were fully set forth in preceding chapters of this book. The strains caused by irregular expansion, therefore, cannot produce distortion of the admission-valve seats or breaking of the stay edges of the exhaust ports, which are now cut in the solid wall instead of being cored out in the casting. The cylinder bushing is split in two halves, the joint being made in the middle of the exhaust slots, so that expansion and contraction of the inner walls can take place unrestricted, especially since the combustion chambers are located at the

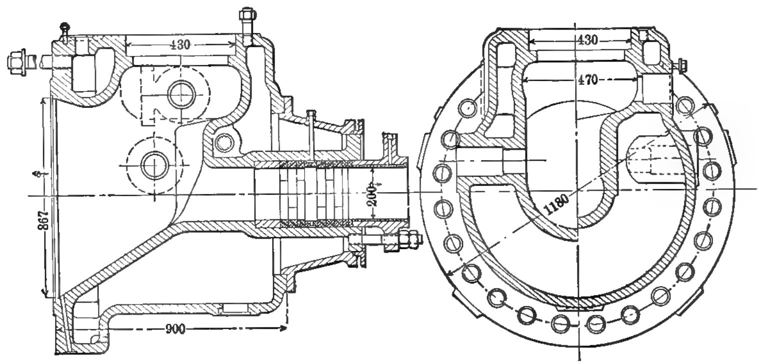


FIG. 108. — Cylinder Head of Double-Acting Two-Cycle Engine.

extreme ends of the system. In the lower part of the wall on which the piston rests no exhaust slots are provided, in order to gain ample bearing surface. Provision is also made to cool most efficiently that part of the wall which becomes heated by the additional friction caused by the weight of the piston. This friction is, however, by no means so great as is usually assumed, it having been found that the piston rings cause much more rapid wear of the walls than does the piston barrel proper. Therefore the number of rings should be kept as small as is compatible with good packing. The other details of cylinder construction can be seen very clearly from the drawings without further explanation.

Figure 108 shows longitudinal and cross sections of the cylinder head. Contrary to four-cycle practice, the inlet valve is mounted on the separate cylinder head instead of on the barrel

of the cylinder proper. Immediately below the inlet valve the igniter plug is mounted, and below this an opening is provided for introducing the compressed air for starting purposes. The area of the inlet-valve cage is very large, making it practicable to inspect and clean the piston head without having to remove the cylinder head and withdraw the piston. As in the older types, the circumference of the piston can be inspected and cleaned through the exhaust slots, to which special inspection doors give access from without. It was mentioned before that the unusually large area of the inlet valve is due to the fact that the proportion of the crank travel during which the charge is admitted to the power cylinder is only about one-fifth of that available in the four-cycle engine. Where the length of the connecting-rod is five times the crank radius, and the crank angle for charging is 80 deg. in a two-cycle, and 220 deg. in a four-cycle engine, the time of opening of the valves is respectively 1 to 275, while the relative travel of the piston during the time given is as 1 to 5.32. Concerning the provisions for water cooling, the arrangement of the stuffing box, etc., the assembly drawing is self-explanatory. For intermittent working and for all services giving widely varying initial temperatures in the engine cylinder, these cylinder heads are not well fitted, since they are apt to crack.

A few years ago Herr Ernst Körting made some interesting experiments on one of the large engines in order to determine the temperatures at various parts of the cylinder. Since there is so little accurate knowledge available on this question I give in the accompanying table the results which were obtained at that time. The cylinder of a 400-h.p. engine was provided with thermometers on the points *a* and *d*, Fig. 109, the mercury tubes of which were located exactly in the center of the wall of the cylinder liner. Special tubes filled with mercury entered through the water jacket into the inner wall up to a point 22.5 mm. distant from the bore, that point corresponding to the center of the thermometer bulb. The measurements were made at different loads on the engine. The table shows how quickly the temperatures of the wall change if the output, or rather the amount of heat developed in the engine, varies, and further, that the temperature of the cylinder near the combustion chamber is considerably higher than it is near the middle of the stroke,

notwithstanding that the point b, on account of its location within the dead-center zone of the stroke, is covered by the water-cooled piston for at least one-fourth of the duration of the stroke. Hence it may be concluded that the temperatures of the wall of the combustion space, which is exposed to much higher gas temperatures than those prevailing at the point b, which is at no time cooled internally, must be much higher than that of the wall at b.

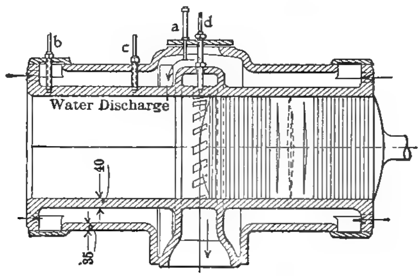


FIG. 109. — Arrangement for Measuring Internal Temperatures.

TABLE 6

TEMPERATURES AT THE INNER WALL OF A KÖRTING ENGINE CYLINDER

Time	3.30	4.00	4.30	4.30	4.45	5.00	5.15
Engine load	¼	¼	½	⅝	¾	⅞	FULL
Temperature of cooling-water discharge (C.)	33	35	36	37	37	37	38
Temperature (C.) of cylinder wall at point b	75	75	83	90	88	92	94
" " " " " " " c	57	57	64	66	62	63	63
" " " " " " " d	156	157	160	165	170	170	170

The maximum temperature measured at full load is 179 deg. C. Doubtless the inner surface of the cylinder liner will become even more heated, especially when the piston is shorter and not water-cooled. Assuming the jacket temperature to be equal to the mean temperature of the cooling water, namely, 29 deg., and the mean temperature of the inner cylinder — disregarding the exhaust slots — as $(94 + 63) \div 2 = 80$ deg., then the expansion of the inner cylinder compared to that of the jacket is:

$$\frac{(80 - 29) \times 0.001067}{100} = 0.0005437.$$

Thus it is evident that even if all of this expansion had to be

taken up by the jacket alone, the stresses exercised would still remain below the elastic limit of cast iron, which, for tension stresses, can be assumed at not less than 0.00075. The effect of expansion, says Güldner, is more severe if the calculation is based on the mean wall temperature t_m, and if the exhaust ports are included in the consideration. Then we have $t_m = (94 + 63 + 170) \div 3 = 110$ deg., and the ratio of expansion referred to the jacket:

$$\frac{(110 - 30) \times 0.001067}{100} = 0.000854$$

which is 13 per cent. higher than the smallest modulus of elasticity of cast iron. Thus it seems advisable to let the outer walls

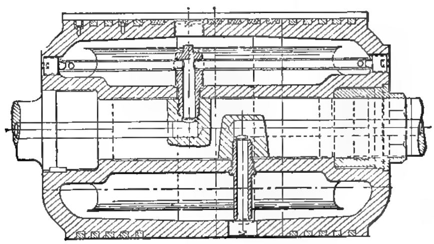


FIG. 110. — Water-Cooled Piston of Double-Acting, Two-Cycle Engine.

participate in taking up the stresses which are exercised on the system by the influx of heat.

PISTON

Figure 110 shows a sectional view of the piston. Compared to the four-cycle type its length is considerable — nearly equal to the length of the stroke, since the alternative opening and closing of the exhaust ports, which are located midway between the two combustion chambers, is performed by the piston acting as a slide valve. The combined weight of a piston of this kind and the water serving to cool it is large, and the builders of the Körting engine prefer to let this weight be supported directly by the lower cylinder wall instead of supporting it by a curved piston rod in a manner described before. The larger engines are fitted with a tail-rod and guide which guarantees a straight-line travel by the piston undisturbed by side stresses

from the connecting-rod. The piston is secured to the rod in the usual way. Water is introduced through a tube from below, and is discharged on top after having passed through all of the space. The smaller self-supporting pistons are equipped with a white-metal wearing surface on the lower wall.

Valve Gear

From cross-sectional drawings can be seen the arrangements made for starting the engine by compressed air, by means of a piston slide valve operated by an eccentric on the lay shaft, the latter running at the same speed as the main crank. The connection of the regulating valve of the gas pump, by means of levers and link rods, with the governor of the engine is also shown. The main inlet valves are opened by cam action and closed by a spring, which must be strong enough to close the valve within the very short time available for that purpose; otherwise a portion of the mixture will be expelled into the overflow channels by the returning piston. Fortunately the internal cylinder pressures against which the inlet has to act are always in the neighborhood of the atmospheric.

It was pointed out before that the proportion of the crank revolution during which the charge is admitted to the power cylinder is only about one-fifth of that available in the four-cycle, and that the area of the inlet valve and also that of the exhaust ports must be proportionately large. When discussing the question of cams versus eccentrics, reference was made to the Körting engine, and the conclusion was arrived at that because the rods have to move at high speed at the moments of valve opening and closing, it was desirable to employ a combination of wiper cam levers which give a gentle opening and closing movement. It would also be obviously better if eccentrics or double tappets were employed for enforcing the closure of the inlet at the proper moment, instead of leaving this important function to a spring.

Recent Improvements in Design

Figure 111 shows a very recent Körting improvement in the construction of the crosshead, its connection with the connecting-rod and the arrangement for discharging the water from the piston

through the piston rod into a trough located below the guides. By unscrewing the gland-shaped nut *n* the rod can be disconnected from the crosshead, and the piston can be drawn out by means of the traveling crane from the rear end of the cylinder, after the cylinder head has been removed, of course.

The correctness of the statement that the pumps form the principal element of cost, which must be reduced in order to cheapen the cost of building this type of gas prime mover, is confirmed by the course of development followed by one of the licensees of the Körting engine, namely, the firm of Klein Brothers, engine builders at Dahlbruch, Germany. While the pumps of the original design possessed cylindrical slide valves operated

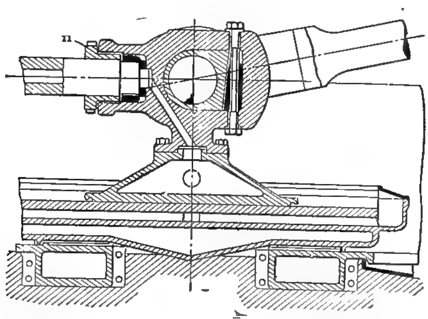


Fig. 111. — Crosshead of Double-Acting Two-Cycle Engine.

through eccentrics and controlling both the inlet and the overflow, the later construction shows slide valves for the inlet but automatic valves for the overflow, while the latest designs show automatic valves for both suction and pressure. The drawing at the end of the book gives a longitudinal and a cross section of the original form, while Fig. 112 gives the latest construction, in which slots are cut in the cylinder wall of the pump at about the middle of the stroke. These slots connect to the suction side of the gas pump and are opened after the piston has completed about 50 per cent. of its suction stroke, and they are closed again after the corresponding portion of the compression stroke.

The suction and pressure valves are of the Hörbiger automatic type and their action can be readily understood from the drawing. Card Fig. 113 shows that while gas is taken in during all of the suction stroke, about half of this volume is dis-

charged back into the suction chamber during the return stroke of the pump piston. It is only after the ports have been covered by the returning piston that the overflow of gas to the pressure

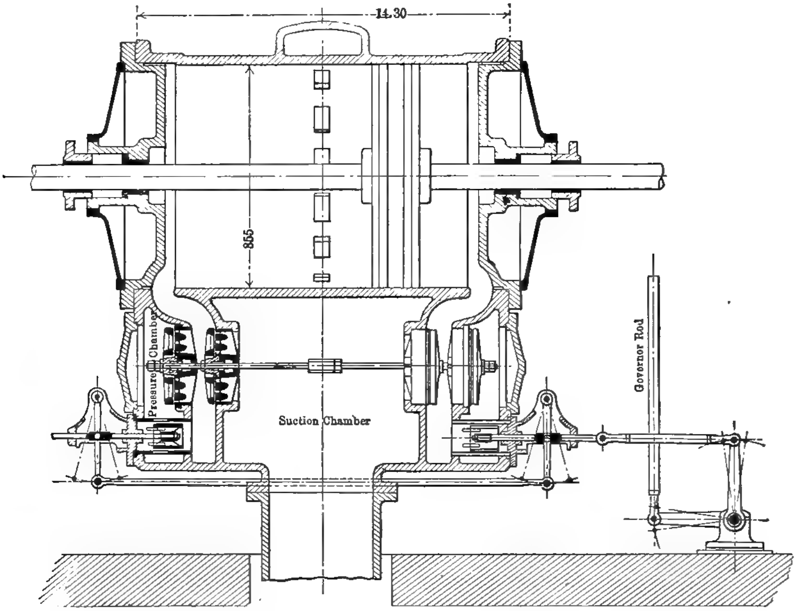


FIG. 112. — Gas Pump, Built by Klein Brothers, Dahlbruch, Germany.

channels begins. During this latter period the governor, through a simple slide valve, varies the opening of a passage between the suction and the pressure side, thereby changing the quantity of gas delivered according to the load.

At no load about 35 per cent. of the pump-stroke volume is thus actually utilized. The rest is dead motion. However, the

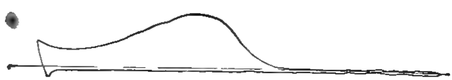


FIG. 113. — Indicator Card from Gas Pump.

work expended in taking in the other 65 per cent. is apparently very small, since the firm gives the pump work as between 6 and 7 per cent. This is a reduction of 4 per cent. from the original

values and proves that the difference in negative work between the two- and four-cycle types is no longer large enough to justify a decision in favor of the latter for that reason alone. On the other hand, the limitation of an engine equipped with a gas pump of above description to only one special gas of fixed composition is in this construction even more rigidly drawn, since the gas pump cannot deliver a larger volume of gas than what corresponds to 50 per cent. of its stroke volume.

Everything considered, however, the latest pump construction of Klein Brothers is a decided step in the right direction, reducing as it does the cost of building and increasing the reliability of operation, the latter factor being by far the most important for large work. With the cylindrical slide valves formerly used, the dust in blast-furnace gas, especially when the gas is saturated with water and forms a tough coating over all contact surfaces, proved objectionable and impaired the sensitiveness of the governor. The new arrangement is much less vulnerable as far as clogging up is concerned.

A further simplification has been introduced by the Kleins in the design of the valve-actuating mechanism. One of the objections raised against the two-cycle engine of the Körting type was that the secondary shaft, revolving as it does at double the speed of the secondary shaft of the four-cycle engine, must depreciate quicker, and that the surfaces of cams and rollers especially would wear out faster. Fig. 114 shows a recent solution which eliminates this objection entirely. As in the four-cycle engine, the lay shaft runs at half the speed of the main crank-shaft. An eccentric *e* oscillates the rocker-arm *a*, fulcrumed at the point *f*, and this arm acts through the roller *r* and cams *c* and *c′* on the cam level *b*, which is pivoted on the outer valve casing. The cams *c* and *c′* on the cam lever transmit the oscillating motion of the rocker-arm to the valve stem, twice in each revolution of the secondary shaft *S*.

Another way out of the difficulty has been attempted by driving the valves and the igniting mechanism directly from eccentrics keyed to the main shaft. Large eccentrics can then be employed, which are necessary for reasons that were fully set forth in the discussion of cams versus eccentrics. At the present time there seems to be among European builders of large gas engines a pronounced inclination toward the adoption of eccentrics,

one of the main arguments advanced being that besides the quiet working and long wearing qualities of eccentrics, their cost of manufacture is smaller, since only lathe work is required, while cams or disks necessitate very accurate cutting; furthermore, the wearing surfaces must be hardened. Altogether there is an apparent tendency noticeable toward the exclusive employment of lathe and boring-mill work wherever possible, in order to reduce the cost of manufacture of large gas engines to that of steam engines.

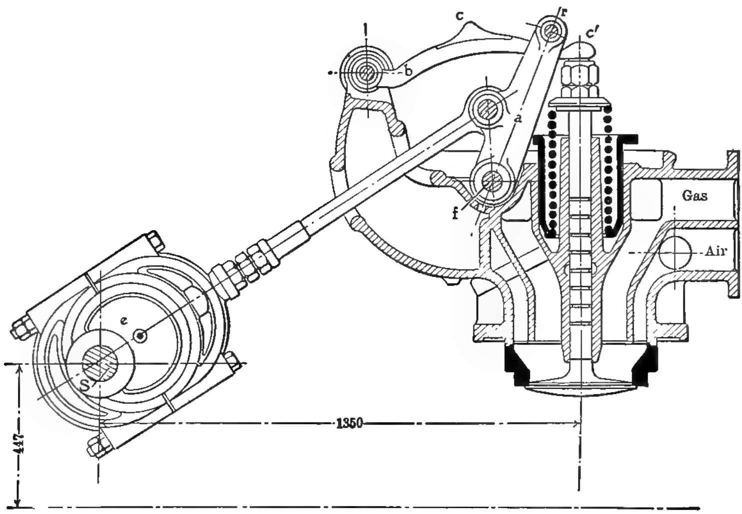


FIG. 114. — Valve-Actuating Mechanism.

The Siegener Maschinenbau Aktiengesellschaft are building their pumps in accordance with Fig. 115. A single eccentric operates all the inlet valves by a connecting-rod. The pressure valves are of the automatic overflow type, being located in the cylinder cover. Both the cylindrical slide valves and the boxes in which they move have oblique openings cut out. When the gas slide valve turns under the influence of the governor, the edges of these openings will either approach or leave each other, thereby effecting a variable retardation of 0 to 10 per cent. at the beginning of suction, which is not ended until during the pressure stroke, with a charge occupying from 35 to 80 per cent. of the total volume. Fig. 116 shows a regulating card from

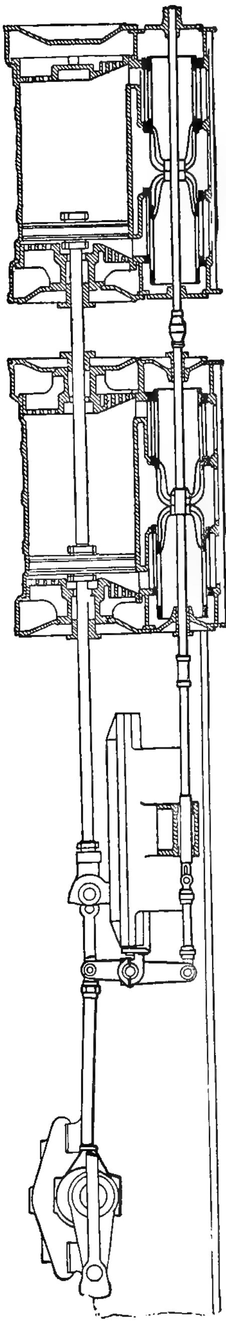


FIG. 115. — Regulation of Pumps as Built by the Siegener Maschinenbau Aktiengesellschaft, Siegen, Germany.

FIG. 116. — Regulating Diagram from Gas Pump.

such a pump. Similarly the air pump can be adjusted by hand to suit the special quality of gas used. This simple device eliminates the back flow of compressed gas. Fig. 117 shows details of cylinder and heads.

Figure 118 shows how the piston of a Körting engine is removed for inspection. A special feature is the ease with which crosshead

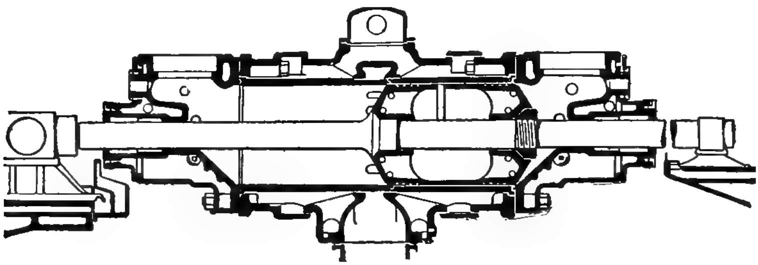


FIG. 117. — Details of Cylinder and Heads.

and piston rod can be disconnected. In addition to the improvements already referred to I mention the following suggestions, which were made relating to the construction of the Körting engine:

Cone-shaped piston head, forming a curved path for the outrushing exhaust gases and for the entering scavenging air, in order that the flow of gases and the change from axial to radial direction may proceed smoothly and without producing eddy currents or interruptions in the even flow. A cylinder composed

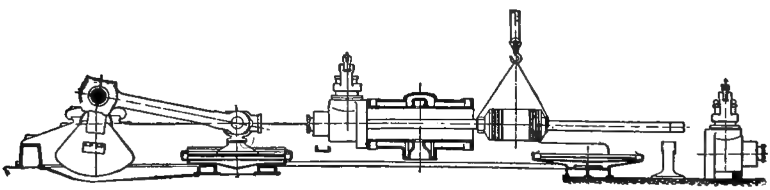


FIG. 118. — Removing Piston in Double-Acting Two-Cycle Engine.

of three parts, one middle portion containing the water-cooled exhaust slots and forming a cylindrical chamber to which are flanged the two symmetrical cylinder liners. Means for regulating the quantity of gas *and* air delivered according to the load, in order to decrease the negative pump work at low loads. A gas pump having a much larger clearance or compression space than

the air pump in order that the influx of gas may be proportionately postponed. Or, eliminating the gas pump entirely and injecting the gas by the stream of air through a nozzle.

Driving Alternators in Parallel

Generally speaking, the success of parallel operation depends on the degree of regularity of the engine, on the weight of flywheel and on the construction of the generator, but before all on the efficiency of the system of regulation employed and on the formation of mixture at no load.

It is known that by means of compressed air the starting of large gas engines is quite as easy as that of steam engines, with the difference, however, that it takes much less time to get things in normal running condition provided a sufficient quantity of suitable gas is available. This is usually the case with blast-furnace and coke-oven gas where continuous working is the rule, and also with natural gas. With modern producers an arrangement is provided which allows, by means of an exhausting fan driven by an independent motor, gasification to be provoked through induced draft, the initial gas being either blown into the atmosphere or returned to the fire chamber until the suitable gas is obtained. Thus starting from cold conditions requires in the worst case from 10 to 15 minutes, while in a steam plant it takes from 30 minutes to 2 hours to get the plant ready for starting.

The rest of the operation of paralleling the generators is evidently identical in both cases. From the moment of giving the starting signal to the moment when both engines make the same number of revolutions, synchronism is established and parallel operation begins, only 3 minutes are required in an up-to-date gas-driven electric central station.

Of the various factors which affect the successful parallel operation of alternators and which find graphical expression in the tangential pressure diagram, the most important is the fluctuation due to the varying crank effort, which oscillates by about 100 per cent. across the mean value, from the positive maximum to the negative minimum. Another factor is the irregularity introduced by the oscillating masses of the driving parts, and the third is the inequality in work output of the two ends of a steam-engine cylinder or of the different combustion chambers of a gas engine.

It is a well-known fact, and one that justifies every legitimate and scientific effort toward the promotion of enforced combustion, that even with a fixed governor, nine out of ten indicator cards taken from a large gas engine will show different characteristics and work areas, if they are examined thoroughly, the variations being mostly visible on the upper part of the combustion line, and being due to the changing location of the gas and air layers and molecules, and consequently to variations in the rapidity of flame propagation. This difference of gas-work diagrams is even more pronounced and may show a deviation of 15 per cent. or more from the normal, if we compare the cards taken from the two opposite ends of one cylinder, or from the four combustion chambers of a double-acting tandem four-cycle engine. These differences are due either to minor variations in workmanship on cams, valves, and gear, or to fluctuations in the gas-admission pipes, or to the influence of other engines connecting to the main, or what not; also to the fact that after parts have been dismounted for cleaning or repair their readjustment is mostly left to the attendant.

In commenting on the problem of operating alternators in parallel, Herr Bonte-Nürnberg in a recent lecture before the Society of German Engineers points out that the more harmful effect of the three kinds of fluctuations alluded to on parallel operation of gas engines is due to the fact that they act at different periods from what they do in double-acting steam engines. While the fluctuations mentioned first occur within the interval of one stroke, the fluctuations which are due to the oscillating motion of the driving parts occur during the time occupied by two consecutive strokes. So far, no difference exists between the irregularities of working of gas and steam prime movers, provided the gas engines are of the double-acting four-cycle tandem type and the steam engines are of the ordinary double-acting type. Hence the difference which actually affects the problem is due to the variation of indicator cards, which with steam is not remarkably pronounced, since there is a constant high admission pressure, while with gas the process of heat influx and pressure development takes place in the cylinder itself and is subject to several irregularities, as already pointed out.

But this difference, which with gas sometimes amounts to a deviation of 15 per cent. from the mean value in one end of the

cylinder, would again be negligible compared to the much greater crank-effort fluctuations, were it not that with steam this period of unequal impulses takes place within the period of two strokes, while with double-acting four-cycle tandem gas engines all inequalities occur only after four strokes have been performed. The power developed in one combustion chamber in excess of the mean value will, therefore, occur only once for two revolutions. In other words, with an engine making 100 r.p.m. the inequality of driving force would be felt fifty times per minute.

This characteristic but unfortunate feature of four-cycle tandem gas engine must be counteracted by the determination, by the designer, of an adequate value for the moment of inertia of the rotating masses. Considering that the latter must not be made too heavy, since an excessively heavy fly-wheel will cause unnecessary losses by friction besides necessitating abnormal shaft dimensions, the engine designer has to choose the value of wd^2 between the lower and the upper critical limits, though theoretically it is more correct to choose a value beyond the latter. But when alternators are equipped with an adequate damping device, paralleling can be made entirely satisfactory without recourse to abnormally heavy fly-wheel masses.

One advantage which the double-acting two-cycle engine possesses over the double-acting tandem four-cycle type is that the period of unequal impulses due to the difference of work rendered in the two ends of one cylinder occurs, just as with steam engines, within the time of two strokes. The effect of this is beneficial either as to the size of fly-wheel or as to uniformity of running. Hence, the Körting engine is, theoretically, better adapted for driving alternators in parallel, if the limitation to low speeds did not militate against it, causing a greater capital outlay for the generator.

Application in the Varied Industries

The majority of two-cycle engines that have so far been installed in continental iron-smelting plants, namely, about 100 engines aggregating a total capacity of 100,000 h.p., are of the original Körting type. Of these, about 50 per cent. serve for driving blowing engines, about 42 per cent. are used for dynamo drive, 4 per cent. for rolling-mill service, and the rest for pumping.

From the distribution of uses it is evident that the application of these engines for blowing service is by far the largest; for services with widely varying loads and temperatures, like rolling, and for intermittent working, they have proved less fit, owing to troubles with the cylinder heads.

There are in service to-day in the German iron industry 150 gas engines of various types aggregating 180,000 h.p. which are used for blowing work, 220 gas engines aggregating 230,000 h.p. for driving dynamos, and 12 gas engines of 20,000 total horse-power for driving rolling mills. Of this total a little over one-third are two-cycle engines. If we consider that in 1905 the American iron industry, with an output of 23,360,258 tons of pig iron, surpassed the combined output of Germany and England together, which countries produced 10,987,623 and 9,746,221 tons respectively, it will be conceded that the truths or facts about the economy of gas power have not been sufficiently impressed on the ironmasters of the United States, for only at the Lackawanna works in Buffalo and at several plants of the United States Steel Corporation do we find to-day an indication of progress in the direction outlined. Some comfort may be derived from the fact that the 40,000-h.p. plant at the Lackawanna works, which is equipped with Körting engines, is the largest aggregate of gas power in the world, the next in capacity being in Germany with 36,600 horse-power.

A few words may be added just here on the much discussed question of the selection of types by which ironmasters are invariably confronted when considering the application of gas power in their works.

The factor of fuel economy, which is highly important when considering the relative merits of gas and steam power, does not enter into the problem when deciding between the two- and four-cycle engines, because, first of all, there are no reliable tests available which would allow one to arrive at just conclusions as to the superiority of one type over the other, and secondly, because it is really of very little importance whether one engine consumes a few hundred cubic feet of gas more per day than does another, for it is only when the gas that is thus saved can be stored or used otherwise that these gains have any real value, and in the majority of places this is not the case.

Therefore, the first point that comes up in the comparison of

the two classes is that of initial capital outlay. Owing to the greater simplicity of parts, which was fully set forth in previous chapters, it should be possible to build engines of the Körting type cheaper than four-cycle tandem engines. The element which, with the present construction, militates against a reduction of the price cost of building is the pump and its regulating and valve-actuating organism. Hence, continental firms are constantly trying to simplify that member, as we have seen.

Another consideration, and one that is sometimes no less important, is that of floor space occupied. We have observed that in the standard combination where the blowing piston is directly coupled to the tail-rod of the gas engine, the length of the complete unit is considerable and, therefore, where floor space is a limiting condition, the two-cycle type will be preferred.

Furthermore, the item of operating cost depends largely on the two factors, cost of repairs and wages for attendance. The provision of skilled labor for a gas plant is regarded as one of the difficulties that militate against the more general adoption of gas power in this country, though it is conceded that no greater intelligence is required to operate a gas engine than to run a steam-engine and boiler plant.

However that may be, under the conditions that prevail at present it is certainly the most economical policy to select the simplest and most reliable engine available, especially if such hard and continuous service as blowing is to be rendered. While, it was said, for intermittent working and widely varying loads the cylinder heads are apt to give trouble, the absence in the Körting type of engine of exhaust valves, which form the most delicate organism of a large gas engine, is an undeniable advantage, but one that is usually more appreciated by the operator than by the owner. Exhaust ports of ample proportions are apt to increase considerably the reliability of a gas engine and will never give any trouble, at the same time allowing part of the dirt contained in the gas to be blown off through the slots. Finally, there are the advantages of excellent speed regulation and ability to start with a load, which are in favor of the Körting type for driving generators, while the limitation to slow speeds militates against it. From 80 to 100 r.p.m. and piston speeds from 600 to 700 ft. per minute represent the maximum attainable with the present type.

That the double-acting two-cycle engine, as at present constructed, though admirably adapted for blowing service, pumping, etc., has only a limited field of usefulness is best proved by the fact that Körting Brothers as well as their licensees have taken up also the building of large four-cycle engines of the double-acting tandem type, in order to be able to meet all demands. Unfortunately the Körtings have abandoned the standard type as represented by the Nürnberg, Reichenbach, Deutz, and other leading builders, and have arranged the inlet and exhaust valves one above the other in a special chamber located on one side of the cylinder. Of course the dismounting of the exhaust valves is facilitated thereby, but the fact that other large builders have tried this arrangement and abandoned it again in favor of the location of valves on the top and bottom ends of the cylinders justifies the conclusion that the latter arrangement is preferable.

Test on a 600-h.p. Körting Engine

In Figs. 119, 120, and 121 the results of a series of tests made on a 600-h.p. Körting engine of the type discussed in the preceding chapter are presented. The engine was running on producer gas made from anthracite coal. The dimensions of the principal engine parts are given in Fig. 119, which also shows the various other items of interest, namely, net indicated horse-power, n_i; effective horse-power, n_e; total pump work, $n_l + n_g$; indicated horse-power of gas and air pumps respectively, efficiencies, etc. While the curves show the actual values of these items under varying load conditions, the data designated under tests *A*, *B*, *C*, and *D* give their mean value, and the results marked at the bottom give the average of tests *C* and *D*. The curves bring out very clearly what relations the various items, such as the total pump work, bear to the indicated and the effective horse-power output. Of course, it must be remembered that the engine tested was of the original Körting type, not embodying any of the various improvements in construction which have been introduced since, and which have effected considerable savings, especially in the loss by negative pump work.

Figure 120 shows the load curve during the test. The mean indicated work averaged 779.4 h.p., or with an assumed mechanical

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efficiency of 78 per cent., 608 effective horse-power. The average consumption of coal at this load was 0.787 lb., or a little over $\frac{3}{4}$ of a pound per effective horse-power. In studying these data sight must not be lost of the fact that they refer to metric horse-power, and that 1 metric horse-power = 0.986 English horse-power. With a 13,000-B.t.u. anthracite coal at $5 per ton the consumption in the producer was about 10,000 B.t.u. and the cost 0.22 cent per effective horse-power-hour. With anthracite at $3.50 per ton the fuel cost per brake horse-power-hour would be 0.13 cent. In all cases it is less than one-quarter of a cent under the assumed load conditions.

Since in modern European practice lignite and peat are the

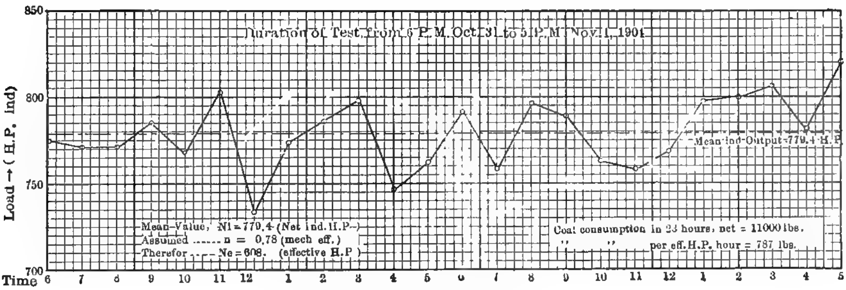


Fig. 120. — Load Curve.

fuels used for the generation of power in gas engines — on account of their cheapness, general availability and other desirable characteristics — the cost per brake horse-power-hour is even lower. A high-class modern steam engine of the same capacity and working under similar load conditions, in order to be able to compete with the engine under discussion, would have to burn under the boilers slack coal costing $1.80 per ton delivered at the boiler house, and even at that the cost per horse-power-hour would be 0.26 cent at best. If the comparison were made on the basis of the respective plant fuel costs, then the stand-by losses caused by intermittent working and varying plant load factor would put the steam plant even at a greater disadvantage. In the particular case here presented it is clear that even in localities where lignite and peat are not available, or where producers for the successful gasification of these fuels have not yet been de-

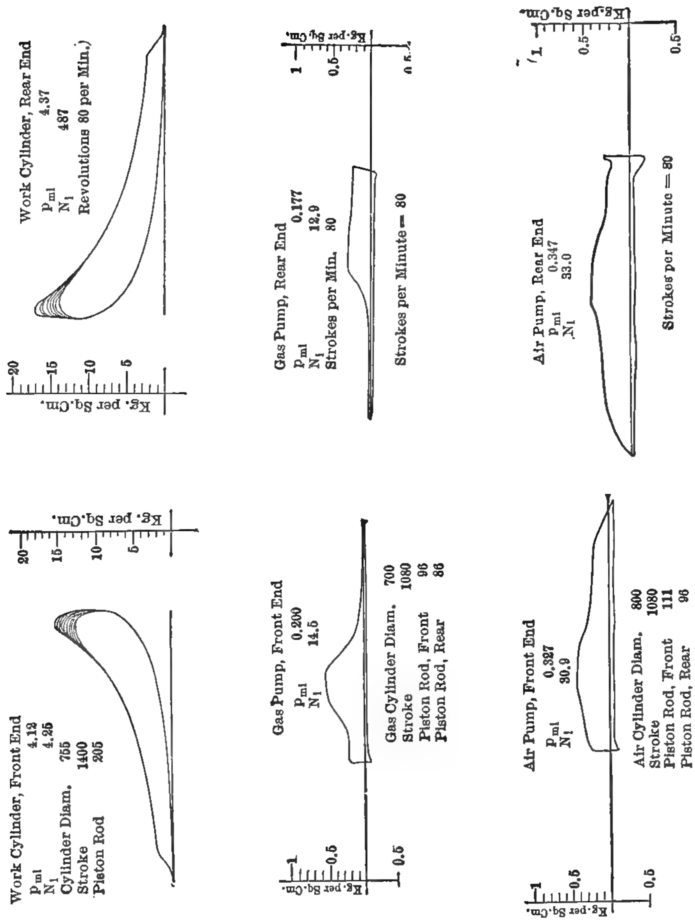


FIG. 121. — Indicator Cards from Cylinder and Pumps of 600-H.P. Double-Acting, Two-Cycle Engine (Körting Type).

veloped, and where anthracite or coke must be used as producer fuel, a reduction in fuel consumption of 50 per cent. or more can be secured through the adoption of an independent gas-power plant, against what is attained with any other form of power generation.

Figure 121 shows the diagrams taken from power cylinder, gas pump, and air pump, indicated at both ends of the cylinders. The mean indicated pressure of the front end of the power cylinder is 60.6 lb., that of the back end 64.2 lb. The corresponding

pressures in the gas pump are 2.9 and 2.6 lb., and in the air pump 4.8 and 5.1 lb. respectively. On the diagrams showing the internal working process of both ends of the power cylinder about ten cards have been taken under identical load conditions. It is evident that while the superimposed compression and expansion curves match each other quite regularly, the combustion lines, which represent the period of heat influx and development, show considerable deviation. This irregularity of combustion becomes the more remarkable the larger the engine and the larger the space which the flame has to traverse from the point of ignition throughout the mass of gas. It is quite certain that the future development of gas engines will do away with this weak point in the working process of the internal-combustion engine, together with the other unfortunate characteristics, namely, premature ignition, after-burning, and back-firing, all of which are drawbacks inherent in the cycle. By proper construction they can be reduced to a minimum and their harmful effects on the operation of the engine be counteracted, but they cannot be eliminated entirely. This can only be done by taking recourse to a new continuous-combustion cycle, or rather by reviving the old Brayton cycle, and providing novel means for enforcing combustion.

VIII

VARIOUS ENGINES AND DETAILS

Deutz — Cologne. Plate I

The products of this largest German firm of gas-engine and producer builders conform in all principal details to the general standards which were studied in the preceding chapters. As a matter of fact, a great deal of the pioneer experimental work was done by the Deutz engineers. One thing that hampered the successful development of large engines at Deutz for some time was that the builders concentrated their energies in former years exclusively on the smaller types. In 1901 the first large double-acting engine was designed, and since that time some fifty engines aggregating a total capacity of 50,000 h.p. have been constructed and installed by the Deutz firm.

A peculiar feature of their earlier cylinders was that they were composed of three separate parts, the middle one, or barrel, being single walled, and the two outer parts containing the valve cages. All edges and corners in the combustion chamber were carefully rounded, so as to avoid the possibility of cracking. In the latest designs all internal forces are transmitted to the external or jacket walls through elastic connections. A separate cylinder liner is used, which may be made of specially suitable material and which is capable of expanding longitudinally.

The stuffing box consists of a series of self-springing rings and chambers, and does not differ materially from other makes previously referred to. The large ring channel in the middle is connected with the exhaust pipe and serves for the escape of small quantities of gas which may leak through the packing. The box cover is pressed against the cone-shaped packing rings by a number of spring-loaded nuts. The springs are located outside the box, so as to remain cool and not lose their resilience. Any faults in the operation can thus be readily detected.

Quantity regulation is employed, special balanced gas- and air-admission valve serving to throttle the mixture in proportion to the load. It is operated from the same lever which actuates the main inlet valve. The fulcrum of the small movable lever which is linked to the larger fixed one is shifted by a gear arrangement from the governor, thereby changing the hight of lift and the active cross area for the inflowing mixture. The back pressure of the mixing valve on the governor is very slight and the valve itself is easily accessible, much more so than it was in the former construction, namely, concentric to the main inlet valve. The closure of the mixing valve is, in the larger sizes, enforced by spring pressure, so that dust or tar cannot interfere with its proper working.

Inlet and exhaust valves are operated from the cam shaft by the ordinary arrangement of swinging rods, joints, and roller levers. One cam serves for both inlet and exhaust valve, the latter being balanced. The roller levers are pivoted to eccentric bolts so as to be capable of adjustment. By disconnecting a single bolt of the valve gear, the exhaust-valve spindle is freed and may be removed together with the valve cage for inspection.

Cockerill — Seraing. Fig. 122

These engines have undergone frequent changes in design, and there is little similarity between the original "Simplex," as constructed by Delamare, and the present type. One feature that is peculiar to the Cockerill design is that the frame is formed of two box girders carrying the cylinder. These girders are joined by tie bolts to others that contain the slides and carry the crankshaft bearing. Another feature is that the cylinder covers are not attached to the central body by studs screwed into it, but joined by tie bolts bolted to flanges on these covers. These bolts are thus subjected to tension, and, similarly, the body of the cylinder is subjected to a compression stress of the kind which best suits such metal. This arrangement is based on the same principle as that which led to the adoption of tie bolts in the construction of cylinders, namely, to reduce the effect of tension forces on the wall system by increasing the pressure forces. The piston is composed of two halves with double walls, each half permitting water circulation, the two halves being bolted together

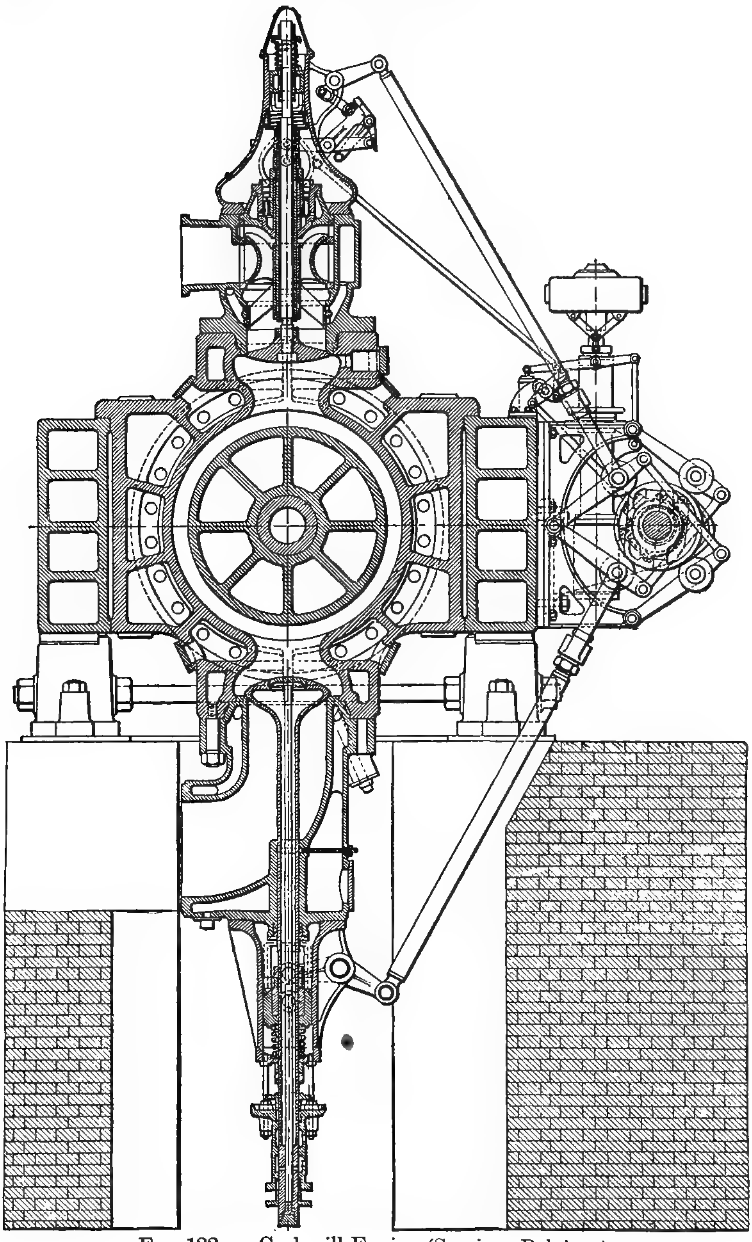


Fig. 122. — Cockerill Engine (Seraing, Belgium).

with an india-rubber joint. This construction has proved excellent in practice. There is nothing else in the general design or in the assembling of parts which would require discussion beyond what has been said in previous chapters. Both systems of quality and quantity governing are employed, the former being fitted on engines for driving electric generators, the latter on such as are intended for blowing service. The reasoning of the makers is that constant compression, which is necessary for the economical production of electricity, might become troublesome when the engine is of the single-cylinder type. It happens that the blowing apparatus may be perceptibly slowed down, and then it might be that the centrifugal force of the fly-wheel would be insufficient for passing the dead center at the time of compression, especially if a misfire had just previously taken place. It is claimed that the system of quality regulation employed confers on the double-acting engine very even running, allowing alternators of fifty periods to be coupled in parallel easily.

Thyssen & Co. — Mülheim

The peculiarities of the quality method of governing, which were explained before, induced the designer of the Nürnberg engine, Mr. Richter, to improve the valve gear, with respect to the formation of the mixture in the engines recently constructed under his direction for the firm of Thyssen and Co., Mülheim-Ruhr. As shown by Fig. 122a, a balanced double-seated valve is combined with a sliding sleeve on the same spindle, which, when the gas valve is shut, permits the admission of pure air to the inlet valve through a slit which is always open. If the gas valve is lifted, the sliding sleeve increases the area of the air passage regularly with the motion of the gas valve. The object of this valve gear is to obtain as regular an acceleration and retardation of the air and gas columns as possible, without the partial vacuum, induced by an early cut-off, being too high. Further, as the gas valve is double-seated, a good distribution of air and gas is obtained, and at the same time the acceleration of the air column is utilized to accelerate that of the gas column.

Schüchtermann & Kremer — Dortmund. Fig. 123

The engines of this firm show an interesting departure from the recognized rule of placing inlet and exhaust valves diametri-

cally above each other. The exhaust-valve chamber is situated at the side of the cylinder and is so constructed that the walls are entirely protected from stresses caused by the variations of temperature. The valve with its spindle can in this case be withdrawn upward.

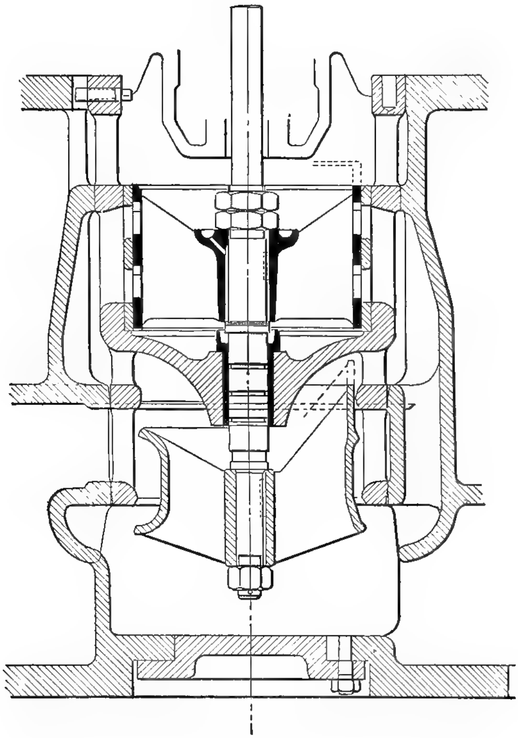


FIG. 122a. — Balanced Gas Inlet Valve (Thyssen-Richter).

Another interesting feature is the governing with a constant mixture and constant compression, invented by K. Reinhardt, Dortmund. It was constructed in answer to a demand by Professor Meyer for a method of arranging the mixture, which, at constant compression, and with increasing quantity of air, renders complete combustion possible, even when the engine is running without load.

The arrangement of this governor is such that two separate air ports and a gas port lead into the cylindrical space above the inlet

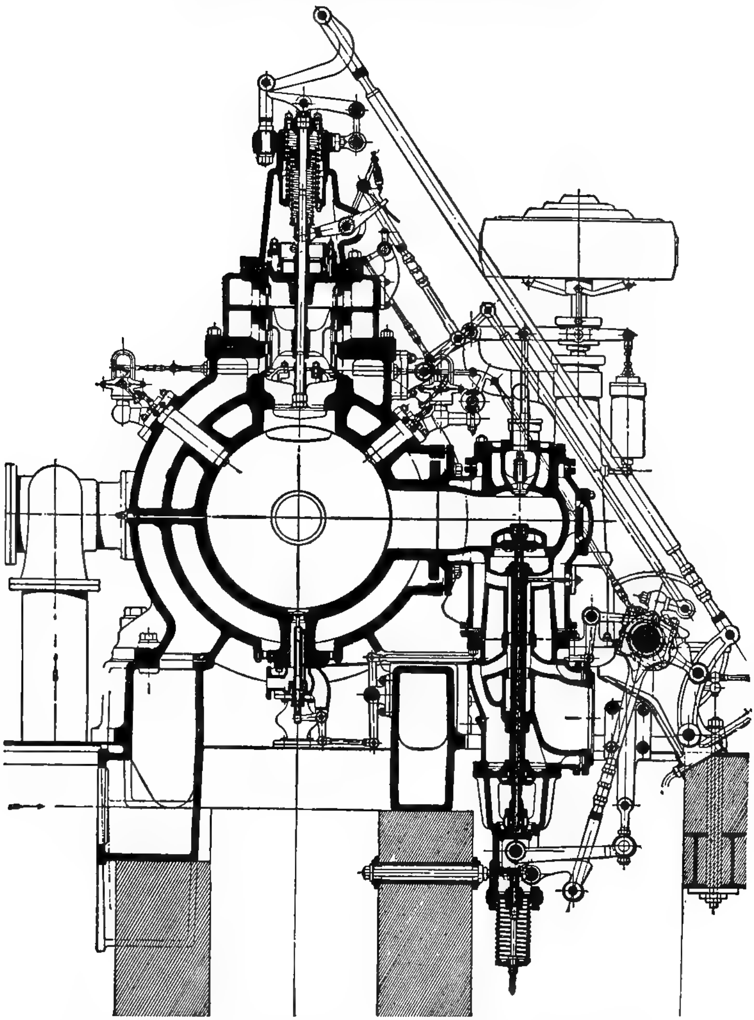


FIG. 123. — Schüchtermann and Kremer Engine (Dortmund).

valve. (See Fig. 124.) The inlet valve opens at the commencement of, and closes at the end of, the suction stroke. In the cylindrical chamber above the inlet valve, and independently of it, a slide moves in such a manner that it first keeps the gas port (I) and then one of the air ports (II) shut, while it allows the admission of pure air through the air port (III), until, at a position of the piston

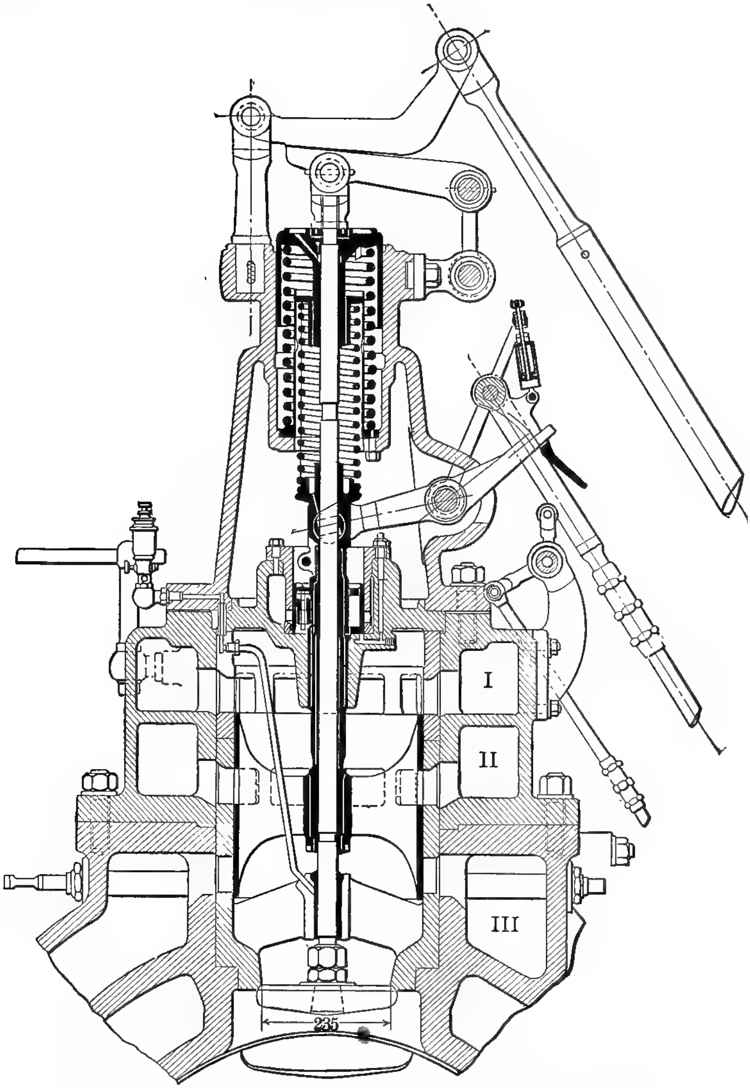


FIG. 124. — Reinhardt Inlet Valve (Schüchtermann-Kremer).

depending on the load at that moment, influenced by the governor, it is suddenly disconnected from its outer mechanism, and through its resulting rapid downward motion suddenly closes the air port (III), at the same time, however, opening the air port (II) and

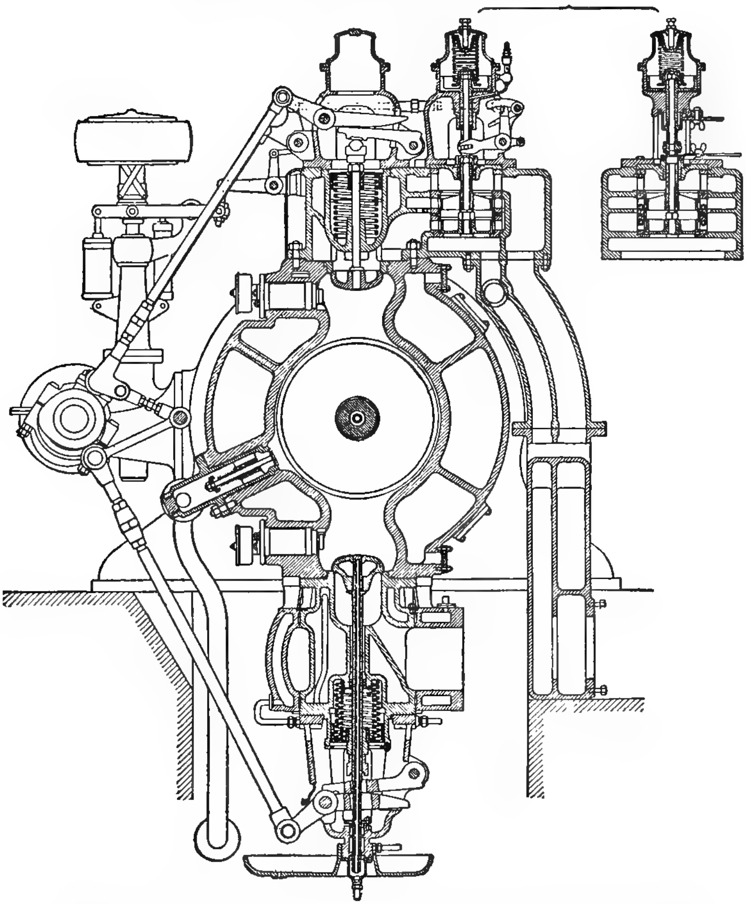


FIG. 125. — Gas Engine Built by Gutehoffnungshütte (Oberhausen).

the gas port (I), so that both air and gas enter for the mixture, both from rest, and through areas which are of correct proportions. Only after the inlet valve is closed does the slide again move upward. Figs. 125 and 126 show cross sections of other notable designs.

BEARING OF COMPARATIVE TESTS

In the preceding chapters of this series repeated reference has been made to the comparative cost of power, so far as the expen-

ditures for fuel are concerned, from various sources; for instance, to the relation between independent suction-gas plants, Mond gas plants, and steam plants. The figures advanced in this connection are merely intended to give some rough idea of what enormous savings in fuel consumption can be made by the adop-

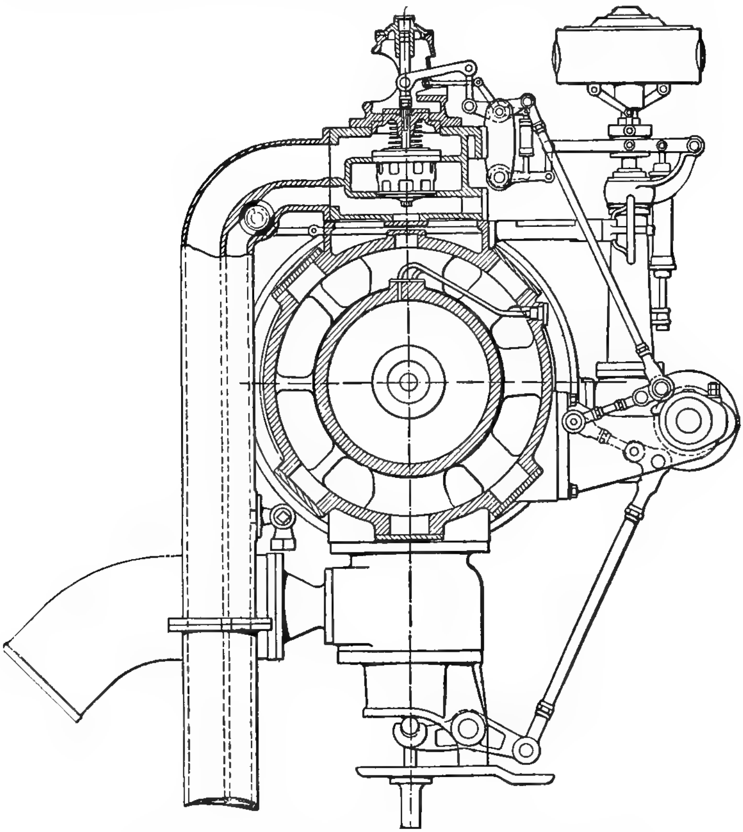


FIG. 126. — Ehrhardt & Sehmer Engine (Schleifinühle).

tion of gas power, without taking into consideration the numerous other advantages, such as the prevention of smoke, etc., and without pointing to one particular engine system or plant. References of this kind are quite valuable in emphasizing the superiority of a modern power outfit over what can be attained by traditional methods of generation. To designate these compari-

sons as documents of the industry, or to attach to them exaggerated importance or scientific value, is a mistake, because not only do they relate to conditions of actual practice only in rare cases, but they are mostly inaccurate and of momentary worth, owing to the constant shifting of the underlying economic agencies.

Referring first to the acute question of gas versus steam, it is almost impossible to find, without construing and adjusting, two analogous cases in which all the conditions affecting the commercial-economy coefficient of a heat-power plant are absolutely identical. Rarely can one find a gas and a steam-engine installation bearing the stamp of similar age and degree of perfection, a state which should preferably obtain in order to arrive at just conclusions. We are liable to quote figures obtained with the latest designs of gas engine without justly discriminating between the types of steam engines available for comparison, whether condensing or non-condensing, whether working with superheat or without, whether employing economizers or other accessories of recent date. And even if we diligently mark down all these distinctions, then the valuation of the superiority claimed for one system over the other will yet be strictly a matter of individual appraising.

Even if we confine ourselves to the determination of the one item of respective plant fuel cost, there are unavoidable differences in every instance which render the results of such investigations rather problematical. Assuming the maximum capacities of the respective gas and steam prime movers to be identical, and that they carry an ideal load which remains constant during the 24 hours of a daily run, then even this apparent similarity of conditions does not suffice as a basis for a comparison, since the process of energy transformation in the gas engine is exhibiting its best thermal performance while the expansion of steam in the engine cylinder is not carried to the most economic pressure limit.

A comparison of performances obtained under load conditions which correspond to the rated capacity of the two types, or to any duty below the maximum, will put the gas engine at a disadvantage, since either compression is reduced or the calorific value of the mixture is impoverished, either of which will reduce the thermal efficiency. So it is only by comparing the results attained throughout the entire range of an identical load of the same seasonal, daily and hourly variations that the values

recorded can be considered as something like definite. But here again it may be objected that identity of type, load factor, characteristics of particular application and class of service, the training of the operating staff, etc., are not alone sufficient; but that a difference in the geographical location of the respective plants, for example, will spoil the comparison, since it is known that the degree of altitude exercises an influence on the performance of gas engines which is indeed of no mean order of magnitude.

If we extend a comparative investigation to the total operating expenses, or still further, to the total cost of production per unit of power output, including fixed charges such as interest, depreciation, taxes, insurance, then conditions become even more complex, and a criterion by which the relative value of the two rival systems can ultimately be judged requires the consideration of so many variable factors that, with fairness to both types, we cannot claim the results obtained to be more than an approximation to the truth.

So to the critical student of the power problem emphatic statements such as are often to be found in catalogues of gas-engine manufacturers, sounding the death knell of the steam prime mover, seem rather ill placed. It is obviously better to convince the discriminating engineer and the public of the merits of our case by presenting the strongest argument of figures and facts, showing what extensive application this form of power generation has actually received, than to offer comparative tests of two rival systems built on an unscientific, and therefore weak and disputable, basis.

If we consider that the world's total output of gas power has increased within the last four years in the ratio of 1 to 5.4, namely, from 181,000 h.p. generated in 327 gas engines, to 1,000,000 h.p. produced in 1000 large gas engines, of which one-half are "made in Germany," one-fourth in the United States, and the rest in other countries, then these figures will establish better than can any argumentation the fact that gas power has become a strong claimant for recognition in the field of power generation, and that it has come to stay.

Rules and Regulations for Testing Gas Producers and Engines

The preparation of the following rules for making gas-engine and producer tests was undertaken by a committee appointed from the Verein Deutscher Ingenieure, in collaboration with the German Society of Engine Builders, with a view to establishing definite general regulations governing such tests. It is desirable, by specifying the important proportions of the examined plants and the conditions under which the results were attained, to take care that these results are not only applicable to a single case, but that they have general value. To attain this end it is necessary that all data should be given uniformly according to a code of regulations such as those here presented.

The execution of such tests is to be intrusted only to persons possessing the required expert knowledge and practical experience. These persons must make a trial plan, or schedule, appropriate to the individual case in hand, which, in many instances, will not require that all of the investigations stipulated in the general code are actually carried out. They must further examine the instruments for measuring or recording purposes as to their fitness, and must compile the results. The following rules, the adoption or selection of which must be left to the soundness of judgment of the investigator, are to serve as a basis on which to proceed.

Object of Investigation

1. The object of a test made on a producer-gas plant can be to determine:

(*a*) The quantity, composition, and calorific value of the fuel consumed;

(*b*) The quantity, composition, and heat value of the gas produced;

(*c*) The degree of efficiency of the producer-gas plant;

(*d*) The separate heat losses in the plant;

(*e*) The quantity of impurities contained in 1 cu. m. or 1 cu. ft. of gas (dust, tar, sulphur, etc.);

(*f*) The moisture contents of the gas;

(*g*) The water consumption of the producer-gas plant, either total or in the separate parts;

(*h*) The mechanical work required for operating the plant, including cleaning apparatus;

(*i*) The duration or time required for starting;

(*k*) The stand-by losses during intervals of shutting down at day or night times.

2. The subject of a test made on an internal-combustion (gas) engine can be to determine:

(*a*) The indicated capacity and the effective output;

(*b*) The mechanical efficiency;

(*c*) The fuel consumption and the heat consumption per horse-power-hour;

(*d*) The consumption of lubricants, separately for cylinder and engine;

(*e*) The composition of water and the heat conducted to the cooling water;

(*f*) The fluctuations in number of revolutions;

(*g*) The composition of exhaust gases.

Number and Duration of Tests; Admissible Fluctuations

3. The number and duration of trials are determined by the purpose of the test as well as by considerations of the conditions of installation and operation, and must be settled and previously arranged according to paragraphs 4 to 8. For trials of special importance the results of which are decisive for contract tests, for penalties or for premiums, this item is to be treated also according to the significance of the interests connected therewith.

4. Delivery tests should be made, if possible, immediately after a plant has been put into actual operation; the delivering firm, however, must be granted a reasonable time for making preliminary trials of its own and for carrying out alterations or improvements then necessary. The duration of this term and other conditions are best agreed upon when making up the delivery contract.

5. In order to be able to get acquainted with the operation of the plant that is to be tested, and to find time for examining the testing devices employed, and to direct the observers and assistants, it is essential that preliminary trials be allowed.

6. If the fuel consumption in gas producers is to be determined, the trial run must be extended over at least 8 hours in the condition of constancy and without interruptions.

7. For determining the consumption of liquid, or gaseous fuel, and provided the condition of constancy is attained, it is sufficient for the higher loads to extend measurements over an hour or so, while for finding the consumption at the lower loads, measurements of even shorter duration are sufficient. To ascertain the condition of constancy the temperature of the outflowing cooling water must be read from time to time. The previous remarks as to the duration of tests are made with the provision that no interruption or disturbance of the trial takes place, and that intermediate readings show only slightly diverging values for the consumption.

8. If only the mechanical efficiency of an engine is to be determined, trials of short duration in the condition of stability are sufficient; but at least ten sets of indicator cards are to be taken.

9. For researches of special importance at least two sets are to be made, one after the other. They can be considered correct only if no interruptions occurred and if the results show no greater deviations than what can be ascribed to unavoidable errors of observation. The mean of the two results is to be taken as the definite result.

10. The extent of the difference between the output and consumption that are guaranteed and the results that are recorded which may exist without justifying a claim of failure is to be agreed upon before making the tests (either when making the delivery contract or when preparing the plan or schedule for the trial). When no other agreement has been previously arrived at, the guarantee is regarded as fulfilled if the figure obtained in the test is not more than 5 per cent. below the value on which the guarantee was based. This margin, however, is allowable only for the maximum output which was promised beyond the guaranteed continuous output. The latter must be rendered by the engine under all circumstances. Within the same limits the guaranteed consumption of fuel or water must not be exceeded even when the load during the test is fluctuating, provided that the engine load did not, in the mean, during the whole length of trial, differ by more than $\pm$ 5 per cent., and for a single case not

more than $\pm$ 15 per cent. from the condition on which the guaranteed fuel and water consumption were based.

Since it is often impossible when making tests to have the internal-combustion engine work at exactly the effective (horse-power) capacity on which the guarantee agreed upon in the contract is based, it is recommended that the agreement shall specify the expected fuel consumption for the higher and lower outputs. The same provision is preferably made with gas producers.

Units of Measurements and Designations

11. When giving pressure data it must be stated whether absolute pressures or gage pressures above or below the atmospheric are meant. Absolute pressure equals atmospheric pressure $\pm$ gage pressure. Atmospheric pressure (zero gage pressure) equals 1 kg. per square centimeter. (One metric atmosphere = 14.223 lb. per square inch.)

12. All temperature and heat measurements refer to the thermometer of Celsius, or Centigrade scale.

13. The mechanical equivalent of heat is taken at 427 meter kilograms (mkg.) = 1 (metric) heat unit = 1 (large) calorie = 3087.77 foot-pounds. (One metric horse-power-hour = 632 calories.)

14. The calorific value of a fuel is to be taken as its lower heating value; that is, the heat which is liberated through the complete combustion of the fuel when the burnt products are cooled down to the original (room) temperature at constant pressure, it being assumed that the combustion water and the moisture contained in the fuel remain vaporized. The calorific value must be based on the unit quantity or weight of original fuel, without deducting ash, moisture, etc., and is to be expressed in metric heat units (1 metric heat unit = 1 large calorie = 3.968 B.t.u.). For both solid and liquid fuels the unit of weight is the kilogram.

The heat value of gaseous fuels is based on 1 cu. m. at 0 deg. C., and 760 mm. barometer pressure, and must be expressed in calories as "effective" heat value, that is, reduced to 1 cu. m. of actual gas analyzed. If nothing special is mentioned, then it is always understood that the heat value recorded has been reduced to 0 deg. C. and 760 mm. barometer pressure. (1 cal / kg. = 1.80 B.t.u. / lb.)

(In this country, the general standard so far recommended seems to indicate for "standard gas" a temperature of 60 deg. F., and a pressure of 14.7 lb. per square inch, corresponding to the usual atmospheric pressure.)

15. The efficiency of a gas-producer plant is the ratio of the heat contained in the gas as produced to the heat of combustion of the total weight of fuel consumed in the plant, both items being computed from the lower heating value. In producer-gas plants having a separately fired steam boiler, it is advisable also to determine the ratio of the heat which is chemically bound in the producer gas to the heat equivalent of that portion of the fuel which is consumed in the producer proper for making such gas.

16. The unit of measurement used for the power or work output of an internal-combustion engine is the (metric) horse-power, equal to 75 mkg. per second. (One metric horse-power = 0.986 English horse-power.) It must be clearly stated whether the indicated power, or the useful or available power, is meant. If not otherwise designated it is understood that the figures refer to the useful or available output.

17. The indicated power of the engine or the indicated work is the difference between the total power developed or work done and the indicated power, or work which is consumed within the engine; in short, the difference between the positive and the negative indicated power or work.

The power required at "no load" is the power indicated when no useful work is rendered by the engine.

18. Mechanical efficiency is the ratio of the useful power to the indicated power of the engine.

19. All consumption figures are to relate to the hour, and if they shall be compared with the output of the engine they must be based on 1 horse-power-hour. If not otherwise agreed upon, these data refer to the useful or available output at full load.

Execution of Tests

20. If the quantity of gas made in a producer or the weight of fuel consumed in an engine is to be measured, then all channels or ducts which are not used in the test must be cut off from the piping which leads to the producer and engine that are to be

tested. This is best done by means of blind flanges. The active ducts, pipes, gas holders, etc., must be examined with regard to leakage and made tight if necessary. Unavoidable losses due to leakage must be determined, especially with gas channels laid in brickwork.

Fuel Consumption of a Gas-producer Plant

21. The kind, number, and duration of tests must be agreed upon according to the general rules designated under paragraphs 1 to 10.

22. The constructive features and the operative conditions of gas-producer plants must be illustrated and explained in the report by drawings, so far as this is necessary for arriving at a sound judgment of the manner of working and of the results obtained.

23. Before making the test the plant is to be examined as to whether or not it is in good working order.

24. The quantity of fuel consumed in the gas producer is determined by measuring the weight of the fuel which is charged into the producer during the trials in order that the producer may contain at the end of the test exactly the same amount of heat — either liberated, or chemically bound in the fuel — that it contained when starting the test. To meet this requirement it is not sufficient that the depth of the fuel bed be the same at the end that it was at the beginning; it must also be taken into consideration what influence the ash and the slag left in the producer, the location of the incandescent zone, the formation of fissures and cavities, the closeness or density of the producer charge, and the chemical composition of the burning fuel particles exercise on the heat contents of the producer.

In order to comply with these requirements the following stipulations are to be met:

25. When starting the test the plant should be in the condition of stability or normal working condition, if possible. This means that after a period of shut-down for cleaning or repairs it should have been in active operation for one or more days, running on fuel of the same characteristics and size, with the same depth of fuel bed, the same skill of attendance as regards the charging or feeding of fresh fuel and the removing of slag, and under the same load conditions that obtain during the test.

26. During the trial the producer shall be charged and poked as nearly in accordance with the requirements for attendance as possible. The level of fuel charge must be the same at the beginning and at the end of tests and should be kept constant during the trial. About half an hour before starting and before stopping a test, the slag and ashes are to be removed. If it is impossible to rake out the ashes during the operation of the producer, the plant must be shut down immediately after stopping the test, the slag must be taken out at once and the producer refitted up to the same level that existed when starting the test. The weight of fuel used for this purpose must be added to the consumption.

27. The fuel consumed during the trial must be weighed, also the fuel which has not been burnt and remains useful; that is, that portion which drops down from above the grate while raking out the slag, and that which is culled out from the ashes as unburnt. The weight of the former may be deducted from the consumption, but not the amount which is taken out from the ashes, nor the coal dust which accumulates in the scrubbers and in the flues between the producer and the engine.

28. To be able to determine the quantity of ash and slag produced during the trial, the ash box must be emptied before the test. If this is not possible, as when an inclined grate is used, the refuse in the ash box must be equalized before and after the run.

29. The stand-by losses during intervals of shutting down at day and night must be determined.

30. In order to get a representative sample of the solid fuel, the following course may be pursued: Of every car-load, basket, or other measure of the fuel, put a shovelful in a covered receptacle. Immediately after the test is over, the contents of the receptacle are to be broken, mixed, spread and quartered by drawing the two diagonals of a square. The two opposite quarters are to be rejected, the two others broken up finer, mixed, and quartered, and the two opposite quarters rejected. This is continued until a sample of some 5 to 10 kg. remains, which is preserved, in well-closed receptacles, for analysis. In addition to this a number of other samples must be put away in air-tight receptacles for use in determining the contents of moisture in the fuel.

31. The composition of the fuel shall be determined by

elementary analysis. Its contents in carbon, C, hydrogen, H, oxygen, O, sulphur, S, ash, A, and water, W, must be given in percentage of weight referred to the original fuel. The contents, in the fuel, of nitrogen, N, can be disregarded. The behavior of the fuel when being heated is to be determined by a coking test.

32. The calorific value of the fuel must be determined by calorimetric analysis. An approximate determination of the heat value can be made on the basis of the chemical analysis by employing the so-called "association formula":

$$81\ C + 290\ (H - \frac{O}{8}) + 25\ S - 6\ W.$$

Testing an Internal-combustion Engine

33. Kind, number, and duration of trials are to be agreed upon according to the general regulations Nos. 1 to 8.

34. The constructive features and operative conditions of the engine must be so illustrated in the report as to enable one to form a correct idea of the manner of working and of the results of operation. Especially important are the type and capacity of engine, diameter of cylinder, and piston rods, piston stroke, contents of clearance space, and other essential dimensions; the normal rate of revolution and the admissible fluctuations; kind and heat value of fuel for which the engine is intended. The diameter of the cylinder and piston displacement are to be actually measured if this is possible.

The contents of the compression space are preferably determined by filling with water. If it is impossible to state the cubical contents of the compression space, then the compression pressure at full load at least should be given. This is done by taking an indicator card while the ignition is interrupted.

35. Before making the test the engine must be examined internally and externally as to whether or not it is in good working order.

36. The number of revolutions of the engine is to be determined by a continuous-speed counter, the records of which must be noted at certain intervals, and must be checked or corrected from time to time by direct readings. If the velocity conditions of the engine are to be investigated it is essential to determine the following items:

(*a*) The number of revolutions during the condition of constancy at maximum load and at no load;

(*b*) The fluctuations in speed at constant load;

(*c*) The deviation of the rate of revolution from the condition of constancy when the load is increased or decreased according to prescription. These determinations can be executed with apparatus of the character of the Horn tachograph. The fluctuations of speed during the performance of one engine cycle above and below the mean value, expressed in parts of the latter, are to be determined by calculation unless otherwise provided.

The degree of irregularity of the fly-wheel velocity =

$$\frac{n \text{ maximum} - n \text{ minimum}}{\dfrac{n \text{ maximum} + n \text{ minimum}}{2}}$$

37. The useful output can be determined either by brake test or by electrical measurement. The dimensions and weight of the brake should be determined before the trial. The electrical measurements can be made on a generator directly coupled to the gas engine. The useful work is computed from the output rendered by the dynamo. The efficiency of the generator is to be determined after one of the methods as laid down in the "forms for valuating and testing electrical machinery and transformers," published by the association of German electrical engineers. If the efficiency is found approximately by measuring the determinable losses, then an adequate amount (say 2 per cent. of the full-load output) must be allowed for losses not accounted for. The apparatus with which the electrical measurements are executed must be calibrated before and possibly after the test. Whether anything besides this gross amount for increased bearing friction and air resistance of the dynamo shall be credited to the gas engine must be determined separately for each individual case.

Whether, in case the useful output can neither be determined by brake test nor by electrical measurements, the code provision for testing steam engines can be admitted as correct for gas engines, namely, to designate the useful output as the difference between the indicated work and the work consumed at no load, cannot be settled at the present state of development, since results of accurate investigations are not yet available.

38. Indicators must be connected immediately to the combustion chamber without employing long piping with sharp bends, and one indicator must be provided for every combustion chamber. For this purpose each compression chamber must contain an opening for $\frac{3}{4}$- or 1-inch Whitworth thread. The same holds true for pumping cylinders. The indicators and their springs must be calibrated before and after the test according to the forms established by the Verein Deutscher Ingenieure.

39. During the test, cards should be taken quite frequently from every combustion chamber and from the pump cylinders. The cards are to be designated by numbers, and the time when each card was taken, the scale of springs used and the number of single cards obtained must be recorded on the cards. At least five diagrams should be taken on one card successively. From time to time diagrams indicated with a weak spring should be taken from the combustion chambers. The indicated work at no load is to be determined immediately after closing the main test and while the engine is still warmed up ready for operation. Care must be taken that the no-load cards are not taken during an acceleration or during a retardation period of the fly-wheel.

Analysis of the Gas Generated in a Producer-gas Plant or Consumed in an Internal-combustion Engine, or of the Liquid Fuel Used

40. The samples for the chemical analysis of the gas must be taken during the trial at regular intervals and as frequently as possible. They must be either analyzed on the spot or preserved in glass tubes closed by melting the ends. The analysis is to determine, in per cent. of volume, the contents of the gas in carbon monoxide, CO, carbon dioxide, CO_2, hydrogen, H, marsh gas, CH_4, heavy hydrocarbons and oxygen, O_2. In addition it is recommended to determine the contents of sulphur (in grams per cubic meter). The gas samples are to be taken from the connection between the cleaning apparatus and the engine.

41. The heat value of the gas must be determined quite frequently by calorimetric analysis, and the burner of the calorimeter should be fed from the gas-admission pipe without interruption. In suction producer plants this can be done by means of a gas pump drawing from the pipe. If conditions should

make it necessary that a sample be taken from the pipe while the calorimeter is shut off, such sample to be later transferred to and burned in the calorimeter, then the quantity of gas burned should not be less than 300 liters (10.59 cu. ft.), in order that the calorimeter can at first be brought into the condition of stability also as regards the overflowing combustion water, and in order that at least 100 liters (3.53 cu. ft.) remain available for two simultaneous analyses. The suction pump, the gas holder, and the piping must be made tight with special care when making a calorimetric analysis of suction gas.

42. The gas meter of the calorimeter in which the heat value of the gas is determined must be calibrated. For determining the temperatures of the calorimeter water, only thermometers with calibration certificates or others compared with such are to be used. The scales must be divided at least into tenths of a degree.

On the basis of the chemical analysis the heating value of gases which do not contain heavy hydrocarbons can be computed from the following formula, if a calorimetric analysis cannot be made:

$$30.5\ CO + 25.7\ H_2 + 85.1\ CH_4.$$

43. The quantity of gas produced or consumed is to be measured by means of a gas bell or gas meter. (Holder drop test.) The cross-sectional area of the bell is to be determined by measurement at several places of its circumference. Consumption tests with the gas bell shall not be made while the latter is exposed to the sunshine.

44. The gas meter must be calibrated and mounted true with a water scale; it must be so filled that the water level corresponds to the normal filling obtained during calibration. Between the gas meter and the engine a pressure regulator or pulsometer must be installed or a large suction space provided so that the water level shows only small pulsations during the pressure fluctuations.

45. At intervals corresponding to the duration of test the following readings are to be made: Position of gas bell at three places or the records shown by the gas meter; the pressure in the bell or in the gas meter; the temperature of the gas when entering and when leaving the gas bell or the gas meter and before reaching the engine; the barometric pressure.

46. If the temperature of the gas is different when measuring the consumption from what it was when measuring the heat value, then the computation must also take into account the increase of volume which is due to the moisture contents of the gas at higher temperatures.

47. The consumption of liquid fuel must be determined either by weight or by measuring its volume. For determining heat value, composition, and specific weight of the fuel one representative sample is sufficient.

48. When measuring the fuel consumption of internal-combustion engines, the consumption of lubricating oil for the cylinder is to be determined at the same time.

49. If the consumption at low loads of a double-acting tandem or twin engine is to be determined, it is not allowable to shut off the gas admission at one or more sides of the cylinders by hand, provided that no other arrangements have been previously agreed upon and are mentioned in the report, or that the governor acts automatically in the way described.

The above extract from the code of rules may suffice to give to the student of gas-power engineering a general idea of the care which must be exercised and of the many niceties which must be observed when testing gas producers and engines in order to arrive at just conclusions. The value of the establishment of standard methods for this kind of work cannot be emphasized too often nor too strongly. Every now and then we read of phenomenal efficiencies recorded in pamphlets and bulletins sent out by manufacturers, and, what is most deplorable, in papers and magazines which profess to appeal to the technical public. Though the expert can at once distinguish from the manner of execution of a test whether or not the results are correct, it is an unfortunate fact that a great many engineers and, of course, the purchasing public are unable to analyze or recognize the fallacy of some assertions which are put forward under a semi-scientific disguise. These people are deceived and afterward disappointed by the performances of the machines when they fail to come up to the guaranteed figures. It is the duty of all earnest workers in this field to protect the buying public from impositions of this character and to keep in mind the well-demonstrated truth that there is nothing which can do more harm to the commercial growth of a technical innovation than misdirected

enthusiasm on the part of the manufacturer, and misused confidence on the part of the consumer.

In concluding this chapter, the following authoritative views on the subject of gas-engine design, by prominent English, Belgian, and American engineers are given:

IX

ENGLISH, BELGIAN AND AMERICAN VIEWS ON THE DESIGN AND CONSTRUCTION OF LARGE GAS ENGINES

ENGLISH VIEWS. R. M. LEONARD

"THERE is not the slightest doubt that the Germans have built and set to work, with more or less success, a greater number of large gas engines than British makers, and they deserve credit for their various notable achievements in this direction. We would suggest that the best British makers at the present time are equally competent, as engineers, to build such engines if the British public were prepared to pay the same prices for them as are obtained by the best German makers. It is a well-known fact that the manufacturing cost per brake horse-power of large gas engines increases with units larger than 250 b.h.p., so that for a really first-class engine, say of 1000 b.h.p., as built by the best German makers to-day, a buyer would have to pay considerably more than for four units of 250 b.h.p., which would give the same aggregate power. It is a matter of common knowledge to those who have experience in these matters, that when the British buyer appreciates this unquestionable fact, he prefers, in the great majority of cases, to have a series of moderate-size units rather than a smaller number of very large ones. When it is remembered that the thermal economy of an engine of 100 b.h.p is at least as good as an engine of 1000 b.h.p., that the ground space occupied by a number of moderate-size engines running at a speed of 150 r.p.m. is no more than that taken up by the same power in large slow-running units, and that the cost of the former is less than that of the latter, it is very difficult, in most instances in practice, to find an argument in favor of the adoption of very large engines at all. Of course, there are cases, particularly in connection with large iron works, where big units

are required, but the foregoing observations deal rather with the broad commercial aspects of the large gas-engine trade as it is found to-day in this country (England). However, the minds of British gas-engine makers are undoubtedly steadily working on the problems of big engine design, and even up to the present time it will be hard to find a single instance where British manufacturers, seriously requiring large gas-engine units, have been put to the real necessity of going beyond British firms for the work.

HIT AND MISS: PRO AND CON

"We have often been asked what are the real disadvantages of the hit-and-miss type of governor for gas engines, as a strong feeling has been fostered by certain gas-engine authorities that it is largely a thing of the past, and that all makers who do not discard it are very far behind the times indeed. As a matter of fact, the only real objection against the hit-and-miss governor is that it makes a high degree of cyclical regularity rather more difficult to attain. In practice, however, this is only a matter of importance where the question of running alternators in parallel arises, but for every other reason there is much to be said for the retention of the hit and miss for engines up to 150 b.h.p. It must not be forgotten that units up to the size just named are usually placed under the care of attendants who are more or less of the unskilled class, and under such conditions the simpler the apparatus the better, especially in the case of those parts which have frequently to be removed for cleaning purposes. When running on producer gas it is advisable to remove the valves for cleaning purposes after every week's run, particularly the gas valve, which is otherwise liable to get stuck up with deposit brought over from the producer. On the hit-and-miss style of governing the combination of parts in connection with the gas valve is usually of the simplest character. The valve itself can usually be taken out, cleaned, and put back within half an hour, and there is nothing about the whole job which any laborer of ordinary intelligence cannot be made to understand after a very short period of tuition. It is submitted that similar merits cannot be claimed for any other form of governing giving equally good results under working conditions, and it may well be argued that, therefore, the hit-and-miss system may very wisely be

retained for single-cylinder engines up to 150 b.h.p. For large engines or multi-cylinder engines it becomes no longer practicable, and some system giving graduated charges to suit the varying loads is to be preferred.

THE DEVELOPMENT OF THE VERTICAL ENGINE

"The vertical engine, though it is being taken up to some extent, seems to make slower progress than its merits would appear to warrant. Its acceptance at the present time appears to be largely confined to those special cases where floor space is strictly limited, and where an ordinary horizontal engine is consequently out of the question. While appreciating all that has been, and is being, done to perfect the vertical type, we would suggest that until makers boldly attack the problem from the point of view of embodying all the good features on which the horizontal engine has survived during the experience of the last 20 years, the vertical engine will not command the confidence to which certain of its obvious advantages would otherwise entitle it. One of the great difficulties experienced in the vertical engines, which have hitherto been made (principally of the inclosed type), is over-lubrication of the piston. It has always seemed absurd to us to suppose that when horizontal-engine makers have, as a result of experience, adopted careful means to regulate the oil supply to the piston to from 15 to 30 drops per minute according to the size of the engine, these precautions should be entirely disregarded in the case of a vertical engine. Yet such is the case, and we frequently find the mouth of the cylinder quite open to the deluge of oil thrown up from the crank chamber by the "splash" lubrication method usually employed. Again, the "air-cooling" effect, obtainable in the open trunk piston of the horizontal engine of moderate size, is entirely lost in the vertical type, where the open end of the cylinder looks into the inclosed crank chamber. These factors alone point to the need of a departure from the usual design, probably in the direction of a separate guide for the piston, so arranged that the piston itself can be lubricated with *clean* oil and not much of it, while the crosshead guide containing the connecting-rod top end may have as much oil as possible from the crank chamber without other than beneficial results. If the foregoing points were care-

fully dealt with, we believe the feeling in favor of vertical engines would be greatly strengthened. Elimination of over-lubrication troubles (in which may be included faulty ignition with missed explosions and back-firing, together with the nuisance of a dirty exhaust) would certainly make the machine a much better job than at present.

RÉSUMÉ OF THE LARGE GAS-ENGINE SITUATION

"English users are conservative, and therefore the demand for such engines in England has in the past been more than met by the one or two firms who have specialized in them. That there is now a demand for large gas engines in England is common knowledge; that it is exceedingly difficult to get delivery of large gas engines of English build is also common knowledge; that in two or three years' time it will be more easy to get large gas engines of English build is again common knowledge. This, we think, sums up affairs, and *when they do come*, the large gas engines of English build will in quality be a superior and much more simple article than the large gas engines of continental build. Questions like the proper method of governing gas engines, the expansion of the working parts and the best form of electric ignition are rapidly becoming concentrated and reduced to small dimensions. Very many able minds are at work upon the subject, and it is not unreasonable to suppose that now it is recognized that money can be made out of large gas engines, the difficulties which have yet to be overcome will shortly be solved. In the meantime, it is not a trait which has characterized, to any great extent, English engineers, that they prefer to produce the supply before they see the demand." Mr. Dugald Clerk advances the following views: "English engineers consider the large gas engine as it at present exists both too heavy and too costly for its power. Personally, I do not believe that sound and continued commercial success can be looked for with really large gas engines until some better solution be found for their present constructive difficulties."

Belgian Views. R. E. Mathot

"The iron and steel industry is the one which has mainly caused the rapid growth of large gas engines, and Germany has

kept at the head of the development owing to the importance of its metallurgical industries. In that country it has been recently stated that among fifty smelting works actually at work, forty-two are already using, or have ordered, large engines for dealing with the gas generated in the blast furnaces or smelting ovens, or coke ovens. This represents 350 units that give an aggregate output of about 400,000 h.p., the largest of these plants being 35,000 h.p., while there are fifteen works using plants of 10,000 to 12,000 h.p. In some of them only provision is made to work with producers in case of need, to keep the plants at work.

"In collieries and coke-oven works, the competition by internal-combustion engines against steam engines is difficult on account of the great number of old ovens from which the available heat can be used only in firing steam boilers. In these installations, however, the number of engines at work or in contemplation amounts to twenty or twenty-five, aggregating a total output of 35,000 to 40,000 h.p. Almost all of the engines used in both smelting works and collieries are of the double-acting form, some of the two-cycle and some of the four-cycle type, the latter being, of course, the more largely applied on account of their higher efficiency.

"An ordinary blast furnace of a daily output (24 hours) of 100 tons of pig iron liberates about 315,000 cu. ft. of gas which is available for motive power and is of an average heat value of 110 B.t.u. per cubic foot. This quantity of gas generates, in steam plants, about 2500 h.p. while it gives with gas engines 4200 h.p., or about 70 per cent. more power. Such figures, of course, may not be expected unless the plants are provided with modern improved features, among which the most important is means for cleaning the gas, which has recently received careful attention from manufacturers of large gas engines as well as from the users themselves.

"To get rid of the general impurities that the gas contains, such as dust, tar, and chemicals, that would be detrimental to the good working of the engines, as well as in view of reducing the temperature of the gas before delivery to the cylinders, thorough cleaning, scrubbing, and cooling are necessary. These operations are effected by means of fans, rotary washers, or the like, that involve a water consumption ranging from 0.25 to

0.40 gal. per 100,000 cu. ft. of gas. The content of dust can by this process be reduced to from 0.3 to 0.2 of a grain.

"The power required for operating the fans and the washers, depending on the systems as well as the amount of impurities to deal with, ranges from 1.5 to 4 h.p. per 100,000 cu. ft. of gas, that is, about 3 per cent. of the power generated from the gas. With respect to the engines themselves, the cooling water required per hour per brake horse-power for pistons and piston pins is from 2 to 3 gal., and for cylinder jacket, etc., from 7 to 10 gal. Lubrication in a good engine can be effected with 1 to 1½ grams of oil per brake horse-power-hour.

"In view of meeting as closely as possible one of the unquestionable advantages of the steam engines with which we have to compete, we aim to build our gas engines with such dimensions that they afford a large margin of power, and although our best engines are capable of mean effective pressures of 90 and 95 lb. per square inch, we rate what may be called the constant working power on the basis of about 75 lb. Our good four-cycle engines show an average thermal efficiency of 30 per cent., relating to the effective horse-power. This corresponds to about 1 brake horse-power-hour on 8500 B.t.u., which is realized in small single-acting engines, as well as large double-acting engines, when working at normal load.

"Now, allow me to select some results of tests made by some of our leading authorities, and some taken from two hundred trials that I have been called to make myself. (See table on next page.)

TESTS WITH DIFFERENT FUELS ON NÜRNBERG SINGLE-ACTING ENGINES

PLANT	No. 1	No. 2	No. 3
FUEL	ANTHRACITE	COKE	ILLUM. GAS
Working load horse-power	107.4	110	152.8
Consumption per indicated horse-power-hour in engine	0.78 lb.	0.93 lb.	15.7cu.ft.
Heat consumption per indicated horse-power-hour in suction producer; B.t.u.	10,850.	10,840	
Thermal efficiency of producer	80%	75%	
Heat consumption in the engine per brake horse-power-hour; B.t.u	6750	6300	6200
Mechanical efficiency of engine	80%	80%	78%
Thermal efficiency of plant, relating to indicated horse-power	36.3%	38.3%	36.6%

OWNERS AND LOCATIONS OF THE PLANTS:
No. 1. Royal foundry of Würtemberg (Wasserflingen).
No. 2. Imperial Post Office at Hamburg.
No. 3. Municipal Electric Station of Greifswald.

TEST WITH ILLUMINATING GAS — GÜLDNER ENGINE

LOAD RATIO	REV. PER MINUTE	M.E.P.; KG. PER SQ. CM.	LOAD; I.H.P.	HEAT VALUE; CAL. PER CU. METER	CONSUMPTION PER HOUR PER I.H.P. REF. to 0° C.; 760 MM. BAR.	THERMAL IND. EFFICIENCY, PER CENT.
½	213.9	4.48	21.	4420	0.3975	33.9
¾	212.8	6.71	31.3	4410	0.347	38.8
full	214.5	8.06	37.7	4430	0.3435	39.
full	210.7	7.76	35.9	4440	0.3145	42.7

TEST WITH SUCTION FUEL GAS FROM ANTHRACITE COAL

LOAD	REV.	M. E. P.		I.H.P.	HEAT VALUE		GROSS FUEL CON. B.H.P. HOUR		THERMAL EFFICIENCY INDICATED
		KG.	LB.		CAL. PER KG.	B.T.U. PER CU. FT.	KG.	LB.	
Full	210	7.6	108	34.9	7780	13.878	0.336	0.739	28.5

"1. Trial of 10 hours with prony brake on a 40-b.h.p. suction producer and single-acting engine of the Maschinen fabrick Winterthur:

"Consumption per brake horse-power at full load, 0.7 lb.; consumption per brake horse-power at half load, 0.94 lb. per hour of anthracite coal of 13,850 B.t.u., including ashes and moisture.

"2. On a similar engine I had already found with illuminating gas a consumption per brake horse-power-hour at four-fifths load of 17.6 cu. ft. of gas, referred to 0 deg. C., and atmospheric pressure, of a heat value of 545 B.t.u. (lower value).

"3. Test made by Professor Schröter on a Güldner engine and producer; piston bore 250.6 mm., stroke 400.3 millimeters.

"It should be remembered that the foregoing figures show low mechanical efficiencies because they relate to engines provided with very heavy fly-wheels in order to obtain extreme regularity of rotation.

"Accurate figures on the consumption of large double-acting engines are unfortunately rather seldom obtainable, those engines dealing with such large quantities of gas that gas holders of sufficient capacity are rarely available for a reliable test. I may mention, however, a trial witnessed by the engineers of both the makers and the users on a double-acting four-cycle engine of 600 h.p. supplied by Ehrhardt & Sehmer, one year ago, to the Königliche Berginspection at Heinitz Saarbrücken, Germany. After four months of constant work and without previous cleaning, this engine was tested with coke-oven gas ranging from 350 to 370 B.t.u., and showed an economy of 8100 B.t.u. per brake horse-power-hour. The mechanical efficiency recorded, with the power under consideration, was 83 per cent. The engine was a new one and was tested under normal load at 150 r.p.m. The principal dimensions are: cylinder bore, 620 mm.; piston stroke, 750 mm.; diameter of rods, 170 mm. The load reached 520 kw. at the terminals of a three-phase dynamo mounted on the crankshaft of the engine. It will be seen that the above figures show a thermal efficiency of about 31 per cent. on the basis of brake horse-power and 37.5 for the indicated horse-power.

"High efficiencies, smooth running, and reliable working are all obtained by reason of the following features of design now applied by almost all European makers. The compression has been

raised to 160 to 190 lb. in order to obtain reliable ignition of the very lean mixtures used for purposes of economy. High compression involves high temperature and we have therefore to design the combustion chamber to allow uniform cooling and free expansion of the cylinder head. We aim also to design the combustion chamber of such a shape that it affords the maximum volume with the minimum cooling surface and facilitates high velocity of flame propagation in the explosive mixture as well as thorough combustion without the sharp explosions which are of such detrimental effect in the old type of hit-and-miss engine now completely abandoned by our representative makers. In fact, whatever the quality of, or richness of, the gas used, in spite of high compression, we aim not to reach initial explosive pressures above 330 to 360 lb. This causes our engines to run smoothly, without pounding.

"Governing is always effected by varying the mixture admitted at each cycle, whether by varying the quantity at constant ratio, or by varying the ratio of gas in a constant quantity of mixture, or by combining both processes. The first method causes, of course, variable compression and, as a consequence, some loss of power due to partial vacuum in the cylinder at low loads, but in spite of this defect it has the advantage of giving the highest efficiency at every load because it results always in good combustion of the mixture, exploding in due time.

"The second method, although being apparently less economical, holds certain mechanical advantages.

"The third method, involving a combination of both systems of variable quantity and variable quality, is claimed by its few advocates to possess the leading advantages of the two former methods, without having their weak points. But the combined system leads to the use of somewhat complicated mechanical arrangements and its reliable operation might therefore be questionable.

"The most rational course seems to consist in the selection of that one of the first two methods which suits better the character of the work the engine has to deal with.

"In the case of high-speed engines supposed to run at a nearly constant number of revolutions, as for driving electric alternators, spinning mills and the like, the inertia of the principal reciprocating parts becomes an important factor of smooth working.

The reciprocating masses should therefore be kept at a constant speed and the system of governing by variable quality should consequently be preferred, because it gives constant compression.

"In the case of slow-speed engines such as are used for driving blowing plants, pumps, rolling mills, etc., which allow variations in the number of revolutions to the extent sometimes of 50 per cent., the system of governing by variable quantity with constant quality of mixture will answer the purpose, despite the variation of the compression.

"All large continental engines are made of the double-acting horizontal type, and similar to steam engines with valves located at both ends of the cylinder. The inlet valves at the top and exhaust valves at the bottom meet both constructional and working requirements in every respect. In this respect the engines of the Allis-Chalmers and the Westinghouse companies in America are quite up to date. The question whether their side crank is better than our center crank will be solved by future experience, though nowadays it meets better the American requirements as to simplicity and facility of erection, which are due to lack of training of their young engineers."

American Views. Dr. C. E. Lucke

"Gas power, to be worthy of consideration by power-plant engineers, must be considered in large installations by engines of large size, and should not be discussed for small sizes at all. Large gas engines have peculiarities and troubles not possessed by small engines, and comparison of steam engines and gas engines becomes rather more difficult in the larger sizes than in the smaller ones. I wish, therefore, to examine this question of gas versus steam power, and I will divide the subject into headings for the examination of the problem:

"*First.* 'The theoretical possibilities of a perfect gas used in various cycles versus steam used in its best cycles as a method of transforming heat into work.' Such examinations on mathematical and thermodynamic grounds have been made many times, and they have always proved the superiority of the perfect gas cycle over any steam cycle that can be devised. Therefore, on this point I think I may say without fear of contradiction, that the perfect gas cycle is better, and a more efficient means for

transforming heat into work, than any vapor cycle in which the latent heat necessarily rejected is so high or in which the difference between total heats at high and low pressures is so small. This would seem to give the gas engine a superior position, and it is along these lines that most of the discussions in print on the superiority of the gas engines are based.

"*Second.* 'The mechanism for carrying out the cycle in a practical machine.' On this point I can easily imagine an endless discussion. There are, however, one or two considerations that seem to me more prominent than others, and more important at this time, because not generally recognized. The gas engine, in its modern form, that is to say, the form in which it appears in the large sizes, has been through a process of development of only about ten years. We have to-day large gas engines that will run. Ten years ago we did not. We have not to-day, however, a specially designed gas engine for each particular set of circumstances under which gas engines have to work. Builders of gas engines have, therefore, taken this single gas engine that would run under certain conditions, not always clearly defined, and have sold it to perform any kind of work under any other conditions, equally indefinite, and the engine has frequently failed as a result. We are to-day just beginning to recognize the importance of adapting the gas-engine mechanism to circumstances and conditions, and are still discovering what conditions affect its operation and what do not. When all of these conditions affecting the operation have been discovered and engineers shall have been educated to use this knowledge in designing proper mechanism, then and then only shall we have special gas engines that can fairly compete with steam engines. The steam-engine advocates are apt to criticize the gas-engine advocates, and the gas-engine advocates are apt to be too sure of the results of the gas engine. This situation is directly a result of either ignorance of the importance of operating conditions and peculiarities of design, or a deliberate ignoring of this knowledge, which can only be attained by cost experiments too costly by far to be ignored.

"*Third.* 'The availability of the fuel.' In the early days only gas fuel was burned; later on, vapor of the oils; still later, by-products, such as coke-oven gas, and lastly, but most important, gas made from coal in producers. It may be fairly said,

therefore, that in the question of the availability of fuel, the steam engine has no position of superiority over the gas engine, with the bare possibility of the caking bituminous coal in producers as the one exception.

"*Fourth.* 'Adaptability of the gas engine to the work it must do.'

"*Fifth.* 'The skill or cost of the operating labor.'

"*Sixth.* 'The first cost of the machine or plant.'

"*Seventh.* 'Cost of maintenance and repairs.'

"Several other items of a similar nature can be added to this list of points of view from which the comparisons may be made, but all of them hinge upon the one question of 'the design of the mechanism of the gas engine' to enable it to do a special service under all conditions imposed. If it should appear that the mechanism can be made as reliable, as cheap, as easily maintained, as adaptable to the work, etc., in the gas engine as in the steam engine, the gas engine would undoubtedly have a superior place. Unfortunately, this has not yet been proved, and the importance of it is even not recognized by some of the gas-engine builders. The steam engine has been through such a process of development for many, many years, and it is not yet finished.

"Ever since the time of James Watt, we mechanical engineers have been designing steam engines and are still designing them, every day a different one. In other words, we have found it necessary to especially adapt each particular steam engine to the kind of service it has to perform, and to the conditions under which it must work. How different the engines of the locomotive from those of the steamship, and how different these from the engines of a large central power station. How different are small steam pumps from the large steam pumps, and a hoisting from a pumping engine. How different the high-speed steam engine from the slow-speed steam engine; the steam engine using low pressures from that using high-pressure steam.

"We have to-day no gas engine especially adapted to pumping water, no gas engine fitted for driving ships, no gas engine generally recognized as the one for close regulation, no gas engine specially adapted for mill work, as distinguished from electric generation, no gas engine built especially for long life, no gas engine for power purposes especially distinguished for its small

space for horse-power, nor one adapted to producer gas as distinguished from blast-furnace gas, or to dirty gas as distinguished from clean gas. In short, we have not only not yet designed special gas engines for special conditions, but are only now beginning to realize the necessity for so doing. The failure to recognize the necessity for so doing is the cause of much loss of money and much loss of prestige of the gas engine in the power-plant world. I know of only one company building large gas engines, in America, out of a possible list of a dozen or more, that has made any money; practically all of the others have lost money in the business. I know of a great many gas-power plants and gas engines that have been rejected for failure to fulfil contract requirements, and which have come into the courts for public airing.

"This loss of money and these failures, together with loss of prestige, and by the loss of prestige, business, which is its consequence, are due solely to one thing, and that is ignorance of the limitations of the gas-engine mechanism. The builder of the gas engine did not know how to make it particularly adapted to the work. His knowledge was, in many instances, derived from a few experiments in his shops, or, perchance, from drawings and information obtained from Europe, the home of the gas engine. At this stage he was probably approached by a purchaser, who had read in the papers of the wonderful performance of the gas engine, the machine that could produce a horse-power-hour on a pound of coal of any kind — any time and all the time. It was with such an idea as this that the prospective purchaser approached the sales department.

"The builder, having spent so much money on experimenting, trying to get his machine to run and having finally succeeded in making it run, was faced with the demands of the purchaser for a guarantee of 10,000 B.t.u. per horse-power-hour. He may not have ever been able to get as low as 15,000; he may not have ever tested his engine at all because of the cost of large gas meters. He may have been dependent upon the same published reports himself, and in his anxiety to get back his money, he gave into the demands of the purchaser. The engine failed, doing much harm to his business, besides the immediate loss of money.

"Now, the point I am making is not that gas engines are going to fail and continue to fail, but that these contracts were made on insufficient information on the part of the builder and unfair

demands on the part of the purchaser, who, knowing nothing of the subject, allowed himself to be controlled by the public press. The purchaser did not know what was fair to demand, except in accordance with what he had read, much of which was false. The builder, either through lack of time, lack of sufficient capital to experiment properly, indifference, lack of able designers, or refusal to take the advice of good engineers, did not know what his engine could do, or did not care.

"When the public shall have been educated to know what it is fair to demand of the gas engine, and to recognize what a gas engine can do, and when at the same time the builders of gas engines shall have recognized the importance of employing the best talent available to design their engines to meet special conditions, and shall take the advice of these experts, as to the importance of recognizing limiting conditions, then will the gas engine take its place properly beside the steam engine, and not before.

"To the public purchasing gas engines or any other sort of engines for power purposes, I appeal: First, to recognize that the gas engine is at present a factor to be considered in every power proposition, and that it is not to be ignored in favor of any steam turbine, water power, or other system, because, perchance, it is not so familiar; second, to recognize that the gas engine cannot do everything, especially when it is in the one-design form, and that what it can do should be best known to its builders and not to the writers of some magazine article; third, to keep the gas-engine builders informed of your special requirements, and invite bids on every power proposition, whether it seems likely they can meet it or not, and in issuing this invitation meet the builder half-way by not imposing utterly ridiculous conditions.

"To the builders of gas engines I make an appeal as earnest as the one I make to the purchasers of this class of machine: First, employ the best men on general power-plant practice that your money can secure, and consider that man most valuable who with the above information also knows the peculiarities of your engine and that of your competitor, with the limitations of both; second, seek to fill the special needs of purchasers without forcing on the public an engine that any good and competent engineer can plainly see is not adapted to the work; third, properly experiment for the purpose of determining what modifications

of design and detail must be made to meet special service conditions and, when once determined, execute them; fourth, coöperate with purchasers of gas engines or power plants of any sort by exchanging freely all information on requirements and performance, and give up at once the hermit-like attitude of isolation and secrecy heretofore so common."

PART III

THE APPLICATION OF GAS POWER

X

IN THE IRON AND STEEL INDUSTRIES

The Influence of the Adoption of Gas Power on the Productive Efficiency, Capacity and Economy of Iron and Steel Works

Productive efficiency of large iron- and steel-smelting plants, according to views held by metallurgical engineers, is composed and determined by the coöperation of a number of independent departments each of which offers internal friction or resistance to the flow of the product. These departments are the blast and steel furnaces; the casting, stripping, and delivery arrangements and soaking pits; the hot beds; straightening, drilling, and shearing equipment, etc. In an inefficient plant the managing staff must devote much time and energy to overcome the friction losses occurring in each of these branches, and it is by the use of diagrams showing at a glance the points in need of immediate attention that a checking and comparing of working costs and the elimination of leaks can be best accomplished.

In almost all of the converting and finishing processes, which serve to transform the original ore charged at one end of the plant into finished and salable goods (rails, plates, sections) delivered at the other end, power is needed. In some, as for instance blowing, rolling, transportation, the power factor is considerable, while in others it represents an insignificant amount. Since the generation and transmission of electric current has of late become economical as well as reliable, electric centralization is coming more and more into general use, and central stations are, therefore, modern and indispensable requisites of large-scale operation. It was natural that in the early pioneer days of the iron industry one should first begin with a small lighting station, gradually to branch out toward electric haulage of materials throughout the works, electric elevation to the tops of furnaces (blast-furnace hoists), the operating of blast-furnace bells, the tipping of Bes-

semer converters, etc., while lately the electric drive of rolling mills, straight as well as reversing, is an application of no extraordinary occurrence in German practice. The fact that of the total power which is normally required for roll drive in our iron industry (800,000 h.p.), one-eighth is derived from central electric stations shows again what I have said elsewhere, that gas power should be considered before all in connection with central station work. Besides operating the heavy rolls the electric generators serve to drive also the tilting and feed tables for the various passes, the hot saws, hot and cold pull-ups, transfer tables, straightening and rail-bending machines, cold saws and other auxiliary machinery of the mills, which were formerly operated by means of steam power.

To cite just one example from German practice which now serves as a model to the steel industries of all progressive countries, the plant of the "Burbacher Hütte" may be mentioned. Its central station is equipped with three blast-furnace gas engines of 1260 kilowatt, one coke-oven gas engine of 980 kilowatt, and one steam turbine of 840 kilowatt, delivering direct current of 2 by 240 volts, which is used to drive 300 electric motors and an electric railway, besides supplying electricity for lighting the entire plant.

It is gratifying to see that the lavish American iron industry is showing a disposition to turn from "extensive to intensive cultivation." For many years past the plant of the Lackawanna Steel Company, with its imposing capacity of 40,000 gas horse-power, has been the only indication of progressive economy in this particular branch of production. Now new installations are coming forth in greater number.

The Steel Corporation's mammoth new plant at Gary, Ind., the Homestead plant of the Carnegie Steel Company and the South Chicago Works of the Illinois Steel Company have been equipped with modern gas-electric drive, employing 36 gas engines of 4000 h.p. each, or an aggregate of 144,000 horse-power. The Gary and the Homestead plants also employ 12 gas-blowing engines having a capacity of 3500 h.p. each, and delivering 30,000 cu. ft. of free air per minute against a pressure of 18 pounds per square inch. The savings in fuel consumption realized by the adoption of gas-drive and electric centralization makes it possible also to install steam turbines at various places

of the works, where their advantages are indispensable and undeniable.

CONSIDERATIONS AFFECTING THE UTILIZATION OF WASTE GASES

When deciding between the advisability of installing for purposes of long-distance power transmission either steam-driven or hydro-electric plants, the choice may, in certain localities where a sufficient and continuous supply of water is available, result in the ultimate adoption of water power as the superior mode of generation, when it is viewed from the four principal points of consideration: availability, adaptability, efficiency and cost. The claims which hydro-electric engineers advance in support of their equipment are, that water as a source of motive power is available almost everywhere, since the most sluggish stream represents an accumulation of energy which, by the application of modern means, can now be utilized. Further, that its availability for power production, when once harnessed, does not depend upon the good will of labor organizations or the facilities commanded by transportation lines. Finally, that its continuity of supply is beyond the influence of human agencies, being regulated by nature's laws only. These claims cannot, indeed, be set aside as negligible quantities, and they will often shift the decision of water versus steam in favor of the first claimant.

It is obvious, however, that the factor of fuel supply and transportation will carry the less weight the less fuel is used in the plant and the shorter its distance is from the source of supply. Thus gas power, that is, the gasification of coal in producers and engines, will be superior to steam power when competing with water power, because the item of fuel consumption is reduced to one-half and sometimes even one-third of that of steam plants.

In the operation of combined iron and coal industries we find conditions where the factor of fuel supply and cost does not enter at all, and where water power has no chance whatsoever, because waste gases and waste coal are available as a regular by-product of operation, always and in enormous quantities. So long as the production of iron and coke is secured, so long have we a guarantee for the continuous supply of blast-furnace and coke-oven gases and other waste and, therefore, for the uninterrupted generation of power.

While it is generally conceded that the various artificial gases

which are available for the generation of power, in a combined plant, such as blast-furnace, coke-oven, and producer gases, must be cleaned in order to enable the prime mover to perform its service not only at a high degree of thermal excellence but also continuously and without breakdowns, it is not always obvious by which means the different gases can be purified most economically — that is, with as little expense for power, water, and labor as possible; also what is the effect of gas cleaning on the efficiency of gas-fired boilers, gas engines, piping, etc. Further, very little knowledge has been propagated on such questions as: What is the best use that can be made of the gas inside the plant, and which is the most profitable way of utilizing the surplus quantity outside?

I shall treat of the first part of the problem in detail in a later paragraph, and it is the object of this study to lay down such general data as are available on the latter application. It is obvious that with three different kinds of gases available, which show different characteristics, that is, heat value, composition, temperature, and impurities contained, not only relatively to each other, but each in itself at different times within comparatively short periods, the selection of the particular application to which each gas is best adapted is a matter of no little consideration and consequence.

BLAST-FURNACE GAS

Speaking more particularly of the utilization of blast-furnace gas in the iron and steel industry, which affords, indeed, the most complete exemplification of all the conditions which affect the operation of a gas-power plant, it is known that for various well-understood reasons blast-furnace works are preferably combined with steel-smelting plants and rolling mills in order to be able to carry out the entire series of converting and finishing processes which transform the original ore into marketable steel products, all under one ownership and with maximum industrial economy.

There are several distinct uses to which blast-furnace gas can be put in works of this magnitude, and the soundness of judgment exercised by the designer of the plant in the distribution of such uses will determine, on the one hand, the amount of additional solid fuel that is consumed in the plant in the form of coal or coke and that must be supplied by the works management at

extra cost, and, on the other hand, the available surplus power that may be sold to advantage in the neighboring districts or cities, and which will yield remunerative returns in addition to the savings effected within the works.

The question whether the gas that is produced in the blast-furnace plant is better utilized for the production of heat by firing (besides the hot-blast stoves) open-hearth and other furnaces, or for the generation of motive power in driving blowing engines, rolling mills, and central stations, can only be decided after a careful consideration of *all* factors which determine the commercial economy of a plant of this character. Thus we must primarily analyze the relation of the utilization coefficient of the first application, that is, gas used for heating purposes, to that of the second, that is, gas for producing power. In some instances, as with the heating of the hot-blast stoves and the driving of blowing engines, the values of the utilization coefficient and load factor are practically identical; but in others there may be considerable difference. So it will often be found that the utilization coefficient of gas for motive power cannot be estimated higher than from 60 to 75 per cent., while the corresponding item of gas for heating purposes may run as high as 85 and even 90 per cent. This difference is naturally founded on the intermittent working of the power plant with its auxiliaries, the various accessories, like rolls, pumps, hoists, fans, etc., showing together an extremely fluctuating load curve, while the various furnaces work almost all day and night continuously, consuming gas at a nearly constant rate.

The analysis must further embrace a careful comparison of the intrinsic values of the respective fuels which are displaced by the utilization of blast-furnace gas. Thus, if blast-furnace gas is used for raising steam, it displaces coal of inferior quality, while when it is used for firing furnaces it displaces gas coal of higher intrinsic value; and though it is difficult to estimate accurately the gain in favor of the latter utilization in exact figures, it must be conceded that in some cases such application will actually increase the working efficiency of the plant.

Moreover, there is to be determined whether the lower first cost of the heating appliances against those of a motive-power equipment is a decisive factor in favor of the former application, or whether the far superior efficiency of energy transformation in the latter method is of weightier commercial bearing.

GAS AVAILABLE FROM COKE OVENS

In some special cases, namely, when coal mines are located so near the works that they fall into the commercial-distribution radius of the combined iron- and steel-smelting plant, this part of the problem becomes even more complex, since of the total quantity of gas produced in coke ovens about 60 per cent. is used to heat the retorts, 10 per cent. to drive the various appliances of the coking plant — such as washers, pumps, etc. — while about 30 per cent. of the gas is available for outside purposes. Now, the relation of the respective intrinsic values, embracing heat contents, cost of generation, transmission and cleaning, of coke-oven versus blast-furnace gas, must be analyzed, since it may be found advisable to heat the steel furnaces with coke-oven gas of high calorific value instead of with the weak blast-furnace gas, thereby saving the cost of regeneration of the gas and having only regenerative ovens for the air supply, as when natural gas is employed for such purposes.

Assuming a consumption of only 1 ton of coke per ton of pig iron smelted, there is needed for a production of say 1200 tons of iron a day 1200 tons of coke. Figuring on an efficiency of transformation of 76 per cent., 1580 tons of coal are needed for making that coke. The total quantity of gas generated per ton of coking coal averages 28 cu. m. (988½ cu. ft.), so that 442,400 cu. m. (15,623,000 cu. ft.) of coke-oven gas are produced within 24 hours. This, of course, is only an assumed amount, since in modern by-product ovens the quantity of gas produced depends on the quality of the coal coked, on its moisture contents, and on the type of oven, and varies considerably in composition during one coking period. In the latest regenerative ovens of the German Otto type up to 140 cu. m. (4840 cu. ft.) of gas per ton of coal coked are attained, the gas consisting chiefly of CH_4 and H, and having a calorific value of about 4000 calories per cubic meter (448 B.t.u. per cubic foot). With American coals the quantity of gas produced is even greater. About 60 per cent. of this is used for heating the retorts, leaving 40 per cent. for other purposes. This gas has a calorific value of 500 B.t.u. per cubic foot and some 25 cu. ft. per hour of it, when burned in a gas engine, will develop 1 h.p. The total available energy of such a plant would therefore be 10,500 h.p. Of this amount about 10

per cent. is used for driving the coke-oven plant auxiliaries, leaving 9500 h.p. available for sale.

If the coke ovens are located near the steel works the gas may be used in the works for heating steel furnaces, as stated above. In a plant of the above capacity this would mean 1,836,360 cu. ft. of coke-oven gas displacing 43 tons of good coal and absorbing one-third of the total surplus quantity of gas available (5,650,000 cu. ft.). Without deducting the amount for the above application, there is for every ton of coal transformed to coke in 24 hours 6 h.p. available for other uses. For details refer to Chapter XI.

PRODUCER GAS

Nor is this question nearly settled with the foregoing considerations, since in combined plants of this magnitude there are still other resources available, such as inferior grades of coal from the mines, culm piles, etc. These have hitherto been wasted, but by the application of up-to-date methods they can now be fully utilized for the economic generation of heat and power gas, in addition to what is gained as a by-product from the blast furnace and coke oven. Such practice is now finding universal adoption in Germany, since several years of experience with the Jahns type of ring producer and other systems have proved its practical merits beyond discussion. A plant of this kind has done active service in the von der Heydt coal mines since April, 1903, which is a sufficient time for drawing definite conclusions as to results. The fuel used is slack, residue, and refuse which drop from the coal conveyers and tipples; also culm banks, which were formerly wasted. It contains only 25 per cent. of coal and is now fed directly to the producers. In this way 2100 tons of waste material are gasified, per month, giving a total of 14,000,000 B.t.u., or 3245 B.t.u. per pound. The cost of 1000 B.t.u. is 0.005 cent.

Of the heat developed, 13,650,000 B.t.u. are used to generate 3500 tons of steam. One ton of steam from gas-fired boilers costs, therefore, 20 cents for fuel, as against 44 cents from coal-fired boilers, as a certain quantity of steam coal has to be supplied in addition to the waste in order to meet the demand. Part of the gas is used in gas engines for the generation of electric power. The cost of the gas per brake horse-power-hour, assuming a consumption of 9750 B.t.u., comes out as 0.05 cent. The steam cost

per brake horse-power-hour in steam engines is found to be 0.51 cent when steam is raised in coal-fired boilers, and 0.24 cent when it is raised in gas-fired boilers. Figuring on an average consumption of 10,000 B.t.u. per hour per brake horse-power in gas engines, and deducting losses through natural deterioration of the fuel, it can be taken that 1 ton of culm generates in modern producers from 20 to 25 h.p. for 24 hours. Of course, the gas can be used for heating furnaces just as well. For by-product gas producers see last chapter.

It is by combinations of such character and magnitude that the iron industry affords the most striking and comprehensive field for the application of gas power from a variety of sources and for a multitude of purposes. Indeed, leaving aside natural gas, which, owing to its territorial and quantitative limitations, cannot claim consideration in this discussion, we find all the principal sources of commercial gas generation, namely, the blast furnace, the coke oven, and the producer, as well as all forms of transformation, namely, heat, light, electric energy, and mechanical power, and their modes of distribution, represented and combined in this one field. Therefore, economic considerations, commercial questions, and technical research on the production and utilization of gas may always be based on the iron industry as the most fitting subject for such studies.

RELATION OF NATURAL GAS TO WASTE GASES

It was said above that natural gas cannot claim consideration as a fuel for large-scale operations in the iron and coal industries. This, of course, refers only to future activities. When natural gas was first discovered and brought into practical use there seemed to be the general idea that the supply was inexhaustible, and it was sold at low rates and usually without measurement. This method encouraged waste in the consumption of natural gas and was abandoned only after the large companies had obtained control of the business. But the gas which was wasted in the early period of production cannot now be regained by recourse to economic methods of distribution and consumption. The following figures will give an idea of the growth and extent of the natural gas business in the United States: There are now 35,000 miles of natural gas mains in use, transporting and distributing

the product of 20,000 gas wells to approximately 1,000,000 consumers, and furnishing a perfect fuel to more than one-twentieth of the native population. The development in this industry has increased tenfold in as many years, and is growing at present at the rate of $20,000,000 per year. The amount of capital invested in the various companies is not less than $200,000,000, and the market value of the securities of the companies is 50 per cent. more than this amount.

As far as the present production of natural gas is concerned, the increased value in 1905 ($41,562,855 compared to $38,496,760 in 1904) is recorded by the United States Geological Survey to have resulted from a general advance in price rather than from any increase in yield. As a matter of fact the great gas fields of Indiana and elsewhere have shown a steady decline since 1902, and the value last year was considerably less than one-half of the maximum production. And even conceding that in several States large and prolific gas fields are being opened up, this would not be of much consequence to the iron and coal industries as consumers of gas power, who must have a definite guarantee that the supply of fuel on which the constancy of production is founded will be upheld for an indefinite time, in unchanging quantities, and within the commercial-distribution sphere of their works.

Where natural gas is available as a by-product of the property owned by some manufacturing concern, or where it can be had in the immediate vicinity of a plant, then it goes without saying that it will be used, if it can be bought at a reasonable price. It may even be pumped over long distances provided that this operation does not make it non-competitive with the available blast-furnace and coke-oven gases. Owing to its high heat value, which ranges from 900 to 1000 B.t.u., and to its great heat density, it is the ideal fuel for transportation, being greatly superior to coke-oven and blast-furnace gases, especially the latter, which has a thermal value of only 90 to 100 B.t.u. per cubic foot.

A further advantage is that no additional expenditures for cleaning have to be charged against natural gas, when burnt in gas engines instead of under boilers, while with blast-furnace gas a part of the cost of cleaning, and with coke-oven gas the total amount, must be charged against it in addition to the price at which the works management appraises the different "waste" gases. For, when heating boilers, coke-oven gas need not be

specially cleaned and yet will give better results than the weak blast-furnace gas, which must be purified and freed from dust in order that the results attained may be similar to those with coal-fired boilers.

Thus the merits of gas power versus steam power, which will be discussed presently, are less pronounced in collieries where coke-oven gases are available. This is partly due to the fact that the cost of power generation represents not nearly so large an item as it does in iron and steel works, since, unless distribution to neighboring districts is provided or very unfavorable conditions prevail, not more than 4 to 5 per cent. of the total quantity of coal produced (or its equivalent in form of waste heat or waste gases) is required in the mines, when they are equipped with modern economic power plants. It is also partly because, in contradistinction to steam drive, the coke-oven gas engine must be charged with the total cost of gas cleaning, in addition to the price charged for the gas as produced. The latter valuation depends entirely upon local conditions. It is sometimes based on a rate corresponding either to a certain weight of coal of thermal equivalence, the price of which in turn depends on whether it is purchased from other or from one's own mines, or to the amount of steam that can be generated by a certain measure of both fuels, or to that of some other standard of comparison, depending upon local conditions.

In any case the valuation of what is called waste in industrial pursuits is nowadays a matter of no mean importance and is not determined and dependent on purely theoretical and technical considerations, but on practical economic questions which have a decided bearing on the remunerative returns of the capital locked up in the different branches of a large industrial concern.

Summing up, it was said that natural gas is an ideal fuel for heating furnaces, raising steam under boilers, and serving to operate gas engines. The fact that over 100,000 h.p. are generated in gas engines running on natural gas in this country is a better proof of its adaptability to that use than any other argument. But against all these advantages there stands the other fact that the production of natural gas is on the decline, while the demands for gas power are increasing daily. Therefore it is safer to base our claims for future activities on coal as the energy-

supplying fuel, since it is certain that the annual production in this country of nearly 400,000,000 tons can be kept up for at least a hundred years to come.

UTILIZATION OF AVAILABLE POWER GAS

Now coming back to our discussion of the principal conditions which determine the commercial and technical distribution of these various gases within the works, a new problem presents itself. After having decided to apply a certain quantity of a certain gas to the production of motive power, the other no less important question arises whether it is more advantageous to use the gas under boilers for steam raising and to employ steam turbines in the central station, or whether it is more economical to burn the gas directly in gas engines, the points in favor of the first equipment being lower first cost, smaller floor space, less expenditure for up-keep, and no difficulty in securing skilled labor, while the advocates of gas power advance arguments of no less weight, namely, elimination of the wasteful and costly boiler equipment with its danger of explosion, smoke nuisance, etc., and reduction of the item of gas consumption to one-half and less than that of steam drive, depending on the plant's load.

Since earnest and laudable efforts have recently been made on the part of gas-engine manufacturers to reduce the first cost price per unit of output to the level of steam-engine costs, and since the only difference between the two forms of application consists in the employment with gas power of a cleaning plant as substitute for the boiler equipment, the whole controversy resolves itself, seemingly, into the very simple requirement to provide for a gas-cleaning plant, which is superior in economy, as regards first cost, floor space, water consumption, and skilled labor, to a steam-boiler plant of the same capacity. But even this is no longer a correct argument, since it has been found that in order to get the highest plant efficiency with steam the gas for boiler heating must be brought to almost the same degree of purity as when burnt in gas engines. Under conditions such as prevail in Germany the initial cost of an electric generating plant, including the dynamo, is nearly the same for both types of prime movers, when all factors are taken into account, namely, about $50 per horse-power. This will be discussed later. All other objections

are insignificant when compared to the simple fact that by the direct utilization of the gas in gas engines, power can be produced at one-half and less of the cost that is on record for any other form of power generation. Or, in other words, from the same quantity of gas produced we can generate from two to three times as much power as can be had by the application of steam engines. At the Cockerill works in Seraing, Belgium, 700 to 800 tons of pig iron are made per day and it is expected soon to have 26,000 h.p. out of it. If successful and far-seeing firms like Krupp, who had one gas power station of some 12,000 h.p. in constant operation, decided only a year ago to install two further units each of 1000 h.p., and like the Gutehoffnungshütte, who have year by year increased their gas engine plant to some 10,000 h.p. capacity, and if the majority of other large iron and steel works and manufacturing concerns in Germany have done likewise, what more convincing proof for the reliability and economy of gas power can we expect?

When iron works and coal mines are located in the neighborhood of other industrial centers, communities, or cities, and provided they have a sufficient amount of salable surplus power available, the works management is confronted by another problem, namely, to decide which system shall be adopted for the supply of these outside markets. They can have the gas-cleaning or by-product recovery plant put up near the furnace and at their own expense, and deliver pure gas to the power station or works to be supplied, or the owners of the iron works and coal mines can put up the cleaning or recovery plant and a complete electric power station, which may, of course, be combined with the central station of the works, and sell the electric energy to the supply company or works at so much per unit. Which of the two methods is the more advisable to adopt depends entirely on local conditions.

The foregoing reference to the power question was made in order to understand, after a careful analysis of the actual conditions prevailing in the iron and coal industries, what significance the factor of gas cleaning possesses in the general problem of securing maximum industrial economy from the utilization of blast-furnace and other available gas. With certain limitations the same line of thought commends itself also for the design and operation of collieries. But, leaving a detail discussion of the latter applica-

tion for later consideration, I shall first attack the subject from a different point of view, and one that will embrace the enumeration of practical advantages gained by the adoption of efficient methods of gas cleaning in such plants, as well as the cost of gaining them.

EFFECT OF CLEANING ON HEATING AND ON POWER GAS

It was stated in an earlier part of this chapter that there was until a short while ago very little actual experience available on the matter of gas cleaning, and that it was held by eminent authorities that if the larger part of the gritty dust contained in the blast-furnace gas were removed in the dry-dust catcher the remainder would not prove harmful to the stoves, boilers, and engines to which it was supplied. It was also maintained that the gas should never be washed for boiler heating, as any tarry products it might contain would enhance its heating power by increasing the luminosity of the flame. Furthermore, there was the seemingly weighty argument submitted that the cost of gas cleaning, together with the increased plant floor space, were apt to annul the advantages gained from the superior heating properties of the cleaned gas.

Consequently, in the first attempts to utilize the waste gases from blast-furnace plants the hot gas was delivered directly to hot-blast stoves, steam boilers, and furnaces laden with dust and at a temperature of from 140 to 160 deg. C. Needless to say that with such practice it was necessary periodically to shut down the boiler plant for cleaning the settings, besides the cleaning that was ordinarily done as a part of the daily routine of the works, and that the frequent cooling of the boilers subjected them to heavy strains, which greatly impaired their efficiency and necessitated frequent repairs. Furthermore, the heating surface of the boilers would gradually decrease on account of the dust that settled down at a cumulative rate, thereby requiring a constantly increasing quantity of gas for generating the same amount of power.

The lower heating value of uncleaned blast-furnace gas per unit of volume, and its inferior combustion efficiency when containing considerable quantities of fine dust, would anyhow necessitate a larger grate area of boilers, the difference compared to

the employment of clean gas running as high as 10 per cent. At the Cockerill works in Seraing, Belgium, it was found that after cleaning a boiler and putting it into commission again it required with dirty gas 3 hours' time to get up the steam pressure, while by using clean gas this time could be reduced to 1½ hours.

A. Gouvy records a case established by actual measurements where, with a freshly cleaned fire-tube boiler, the consumption of blast-furnace gas amounted to 1925 cu. ft. per pound of water evaporated, while after a fortnight's operation the consumption increased to 3529 cu. ft., or almost double the amount. This increase is explained by the dust accumulating in the fire tubes and forming a thick coating over the heating surfaces of the boiler. It was also shown by experiment that the cleaned gas effected a larger evaporation per unit of heating surface with less consumption.

In hot-blast stoves of the Cowper type the cost of up-keep is not a very important item of expense, since even at present their internal structure can be maintained in good shape for three years and longer. What the cleaning of gas does in this instance is that the heat-radiating capacity of the firebrick is greatly increased, since it is no longer covered with dust and slack, so that with the same quantity of gas higher blast temperatures can be attained and a great saving in coke consumption effected.

Gouvy's experiments prove that for the higher temperature limits of from 650 to 900 deg. C. an increase of the blast temperature by 100 deg. will save from 110 to 165 lb. of coke per ton of pig iron produced. For the lower limits this saving is even higher and runs up as high as 220 lb. per ton of pig iron smelted. Assuming the price of coke to be $3.60, the cleaning of the gas would effect a reduction of the cost of production of pig iron by at least 18 cents per ton, if the temperature of the blast were increased by 100 deg. C. A blast-furnace plant working with very high blast temperatures, such as from 850 to 900 deg., will, of course, be unable to effect a saving in the above sense, but the cleaning of gas enables one to use less gas in the hot-blast stoves and to employ the resulting surplus for heating boilers, which again results in a reduction of the coal bill. At Dommeldingen, Germany, the employment of cleaned gas for heating Cowper stoves has effected a reduction of coke consumption, in consequence of the higher temperatures

attained, representing an annual saving of $8600 for one 100-ton oven.

All these deficiencies of operation, and more especially the considerable amount of manual labor that had to be expended for removing the dust, have served to convince the designers of power plants that it is more economical to clean that portion of the blast-furnace gas which is used for raising steam under boilers; but then again it was maintained, for reasons which cannot very well be defined, that it was unnecessary to extend purification to that other part of the gas which is used for heating the blast. Yet it is clear that the same line of thought that leads to the cleaning of the boiler gas must also bring about similar advantages when extended to the gas heating the blast stoves.

Thus one of the stoves which is now installed to serve as a spare unit for reserve, in order that the capacity of the furnace may be maintained during the period of cleaning of the different stoves, may be done away with entirely, thereby saving considerably in the first cost of the installation. Smaller heating surface, superior combustion efficiency, and higher temperatures in the blast stoves, besides the saving in labor for removing the dust, are some of the other advantages gained. Depending on the design and capacity of the stoves, the percentage of moisture contained in the air, the intensity of radiation, the quality of coke charged with the ore and the composition of the latter, and on the degree of purity of the gas, it is possible to reduce the quantity of gas supplied for heating the blast to from 18 to 25 per cent.

VARYING QUALITY OF BLAST-FURNACE AND COKE-OVEN GASES

One more point, which comes up when studying the physical and chemical properties of blast-furnace gas as an energy-transforming medium, is deserving of consideration, namely, the varying quality of the gas at different stages of the generation process. While the average thermal value of blast-furnace gas lies between the limits of from 100 to 106 B.t.u. per cubic foot, and sometimes even reaches higher values, it often drops down to 90 or 85 B.t.u. per cubic foot in the course of one day's operation. In coke-oven practice the composition of the gas changes even within wider limits. Owing to the working process of the standard type or

four-cycle gas engine, the output of which is rigidly limited by the cylinder suction capacity, the power plant, even when equipped with ample gas storage, is unable to sustain peak loads for any length of time while the energy of its working medium is thus widely fluctuating.

Though the automatic gas-supply system which has been introduced by the writer in the design of such plants reduces this trouble of inflexibility of engines by providing between the source of gas generation and the prime mover an elastic member, preferably a fan running at variable speeds, with its output automatically regulated from the governor of the engine according to the momentary requirements, thereby securing flexibility and overload capacity similar to steam drive, it is yet desirable that regularity and uniformity of the conditions which affect the working of the furnace directly be likewise maintained. Therefore, if the varying composition of the blast-furnace gas is uncontrollable, the maintenance of a constant degree of purity of the gas used for heating the blast, as well as the permanent efficiency of the heating surface of the blast stoves, is imperative, as these features increase the working efficiency of the plant. For it must be remembered that all these various niceties of operation help to reduce the amount of manual labor that has to be expended, as well as the quantity of gas required for generating heat and power to carry out the long series of reducing, converting, and finishing processes, thereby eventually decreasing the coke consumption per ton of pig iron smelted, and hence also the total cost of production.

EFFECT OF GAS CLEANING ON COST OF INSTALLATION

Another factor which has hitherto not been fully appreciated is the influence of the reduction of temperature and volume of the gas, which is effected by the cleaning process, on the capacity and first cost of the installation and also on the cleaning process itself. Consideration of the temperature-pressure relations of a gas, or better the ratio of the increase of density to the decrease in temperature, will show that the gain effected by a reduction of temperature of 100 deg. C. is represented by a contraction of the gas to one-third of its original volume. Now it is obvious that the capacity of an apparatus wherein the gas is

transformed by combustion into heat or power, or in which it is washed or mixed or moved, will be increased in a similar ratio while the efficiency of such processes also becomes better. Therefore, to secure a reasonable degree of engine capacity with blast-furnace gas, which is by far the leanest of all commercial gases, it is necessary to reduce its temperature to some 25 or 30 deg. C. This is, of course, also dictated by other conditions, such as danger of premature ignition, etc.

The range of temperature reduction in blast-furnace work is from about 150 deg. C. to about 25 deg., that is, a reduction of about 125 deg. C., and it can easily be computed what shrinkage is effected by such cooling; also what the effect of the contraction is on the size and dimensions of the conduits, pipes, and channels used for conveying the gas. The latter point is further emphasized by the fact that the gas-cleaning plant delivers the gas to boilers, engines, and stoves under a pressure of from 2 to 4 in. of water, depending on the kind of fan or blower employed, thereby further reducing the bulk of the distributing means and the first cost of the installation.

The foregoing enumeration of reasons may suffice to prove the necessity for subjecting the whole quantity of gas generated in blast furnaces, coke ovens, and producers to thorough purification before utilizing it for heating blast stoves or furnaces, for raising steam under boilers, or for generating mechanical or electrical power in the central station. The constructional details of cleaning plants are discussed later.

THE OUTSIDE DISTRIBUTION OF POWER

A reference was made in the above to the distribution of surplus power from iron and steel works and collieries to neighboring districts. The most desirable means of long-distance transmission is, of course, electric current, though serious propositions have recently been made to pump gas from the coal fields, over long distances, to cities, to be there used for heat, light, and power purposes in competition with the existing gas companies. Of the available artificial gases coke-oven gas is superior to blast-furnace gas for transmission, owing to its greater heat density. In oil regions the employment of oil gas is going to be a factor of competition of no mean importance.

The surplus power which remains available after deducting all requirements within the works may be utilized in various ways. The most feasible and the one most often used is to deliver light and power to communities or cities located in the immediate vicinity of the plant. Where these natural outlets are not available, it is becoming more and more customary to establish a system of power exchange between such works as are located within a certain commercial-distribution sphere relatively to each other, the object being to save in initial and operating cost of plants and to balance the stability of output by a corresponding provision for consumption; in other words, to obtain a constant high-load factor for the combination of works, and last, but not least, to provide for a common and ample source of energy in cases of emergency.

Thus small coal mines which produce good coal for coking purposes, and have sufficient coking capacity, will install a coke-oven gas-power plant which, besides furnishing energy to these mines, distributes electric power in form of high-tension electric current to neighboring mines at a profit, or they will make an agreement with some central electric station to deliver a certain amount of energy at a certain figure all the year round to the said station, whence it will be sold and distributed to consumers at a profit. Since the central station holds similar contracts with a number of individual contributors, and since the agreement provides that in case of a breakdown any contributor may become a consumer, that is, may take energy for emergency uses within his works from the line, it is evident that this arrangement offers an ideal means of making and selling energy under economic conditions profitable to all alike over wide territories, provided that the respective concerns can persuade themselves that a combination of such mutually beneficial character is profitable to their individual aims. Modern tendency all over the world is in favor of gigantic combines, since they offer the only means of securing maximum industrial economy, yielding enormous profits and enabling one to compete successfully with other producers.

The saving effected through these combinations is due, on the one hand, to the elimination of special power-generating units and costly reserves; on the other to the maintenance of a constant high-load factor. The importance of the latter item will be appreciated when it is considered that in some gas-power plants an

increase of the load factor from 25 to 50 per cent. will halve the total cost of power.

For the practical realization of reciprocal policy we must again turn to Germany, where, owing to the close concentration of industrial centers, most headway has been made in the centralization of power. In a recent paper on the production and utilization of power in metallurgical and mining pursuits, Dr. Hoffman, of Bochum, discusses quite a number of such combinations, of which the one covering part of the territory of Rhenish Westphalia is the most interesting, because it is the largest of its kind up to this date. The Rhenish-Westphalian Electric Company operates a network of circuits totaling 1000 km. (620 miles) in length. At present this company has two large stations in operation, and a third is to be built in the southwestern part of its territory, which covers the Ruhr valley from Hörde to the Rhine. At its Essen station, which is in close proximity to the Mathias Stinne coal mine, there are two 7500-h.p. turbo-dynamos, and two similar sets will be running in the near future, besides which several smaller reciprocating-engine sets are in operation. At the Hörde station, which adjoins the Wiendahlsbank coal mine, there are two generating sets of 3800 h.p. each, and two 7500-h.p. turbo-dynamos are being installed.

The price paid by the Rhenish-Westphalian Electric Central Station to the various iron-smelting plants and collieries for their surplus energy is 0.7 cent per kilowatt-hour, according to contract. Owing to its own large power plants, aggregating about 55,000 h.p., and to the fact that it can save the reserves, it is possible to sell energy at a very low rate.

For instance, to large consumers, such as factories, rolling mills, collieries, etc., the charge is 1.4 cents per kilowatt-hour, and for driving motors which run at a constant high-load factor, such as fans for mine ventilation, the charge is as low as 1 cent. This central station has also made contracts with several communities and cities, and has taken active part in the operation of smaller central stations and of electric railroads running through the commercial-distribution sphere of their works. The tariff rates are based on a sliding scale, beginning at 7.6 per kilowatt-hour for light, and 3.5 cents for power, and decreasing in proportion to the consumption to 3.5 and 1.4 cents respectively.

Similarly, those collieries which transform a considerable por-

tion of their coal output to coke are selling their surplus energy to neighboring districts. The largest German coal mine, "Rhein-preussen," will shortly produce 3,000,000 tons per annum, of which one-third is to be coked. With this amount at least 17,000 h.p. are generated in gas engines, while only 10,000 are used in the collieries. The surplus energy is sent in form of electric current, at 10,000 to 20,000 volts, to the city of Krefeld and its new Rhein harbor, where it is transformed and sold at 1.9 and 1.7 cents per kilowatt-hour respectively.

Another and very promising way of disposing of the surplus energy is to utilize it for driving electric railways through the commercial-distribution sphere. This proposition is interesting, both commercially and technically, and has been treated in a later chapter. The employment of cheap gas power is destined to become a promoting factor of great weight in the electrification, also, of long-distance railroads.

ECONOMIC RESULTS OF THE ADOPTION OF GAS POWER

To the attainments in economic production previously recorded I add the report of F. Sellge, on the savings realized from the application of gas power in the iron-smelting plant at Differdingen, Germany. In November, 1905, the consumption of boiler coal was 5300 tons, corresponding to a pig-iron production of 21,400 tons, which quantity was converted and finished in the steel works and rolling mills of the combined plant. After the gas-engine-driven central station had been completed and was put into commission the consumption of coal decreased continuously until, at present, it has reached the extraordinary figure of 500 tons of coal per month, while the production of pig iron has increased to 30,000 tons. The price paid for boiler coal is $4 per ton delivered at the works, so that the total saving runs up to $230,000 per annum. In addition, the expenditures for unloading and handling the coal, the wages for firemen and the cost for removing the slag were correspondingly reduced. Of this total saving about 10 per cent. were due to improvements in steam equipment, two rolling-mill engines of the compound type being installed and central condensation adopted. The remaining 90 per cent. are to a certain measure directly, and to another indirectly, due to the adoption of a gas-engine-driven

central station, in that it became possible to dispense with a few wasteful steam blowers and other machinery after the completion of the new equipment. From these figures from German practice it will be seen that where coal prices are high and where much coke is required in the blast furnaces for smelting the ore, there the advantages of gas power are ernomous and cannot be too dearly bought. A saving of $1.00 per ton is no negligible quantity.

If one keeps in mind the facts that the application of gas power in the iron and coal industries from blast-furnace and coke-oven gases, in this country, disregarding entirely the utilization of culm, will generate in the neighborhood of 4,500,000 h.p. the year around, and, in addition to what is consumed within the works, will liberate an enormous amount of surplus energy which may be supplied to neighboring districts in form of heat or light or power, and again, that the actual saving thereby effected in the iron industry amounts under favorable conditions to one dollar per ton of pig produced and to three or four dollars per ton of finished goods turned out, then considerations of the character developed in this chapter will doubtless be given more attention than they would without referring again to the extreme economic importance of the problem.

The Driving of Rolling Mills

A careful study of all the conditions which affect the operation of driving rolling mills by either steam, gas, or electric power reveals the fact that this question has not been sufficiently clarified yet to allow one to pass a conclusive judgment as to which of the three is the most economical mode of drive to adopt under certain conditions. It would therefore seem proper, instead of venturing on an individual opinion or attempting to predict the probable course of future development, to present here a short résumé of what has been said on the subject by competent authorities. The following is condensed from a series of discussions some of which were originally published in *Stahl und Eisen*, and were later translated for the *Iron Age:*

THE ORTMANN DISCUSSION

"The chief advantage of the steam engine, as compared with the electric motor or gas engine, for driving rolling mills is the facility

with which it adapts itself to the load, responding almost instantaneously to a decrease in the speed of the fly-wheel with more power and quickly regaining the normal number of revolutions. This is rendered possible by the fact that an engine built for a certain load is capable of exceeding it to the extent of 50 per cent. or more. The main disadvantage of this form of power is the high operating cost, and it is on this account that so many attempts have been made to replace it by the electric motor and, more recently still, the gas engine. The question is, which of these two motors offers the greater advantages, not only from an economical point of view, but also, what is frequently of more importance, in regard to the maximum security of operation?

Supply of Current an Important Item. — "For electric driving the first point to be considered is whether a sufficiently large power station is available or whether the current must be specially generated for one or two mills. This is of importance because, on account of the variations in load, the station will at times be drawn upon very heavily and the amount of power used may easily exceed its capacity, while at other times the requirements are very small. If the central station is merely sufficient for operating one or two mills this variation will prove very inconvenient. The trouble could be overcome by the introduction of a fly-wheel transformer for a secondary battery, and electricians would say that the solution of this problem is not at all difficult. From a technical standpoint this is true, but from an economical point of view it is a question whether such an installation would not be too expensive. A power house with a transformer is a costly installation and could only be of advantage if the generators were run by gas engines using blast-furnace gas. A steam-driven central station would be out of the question on account of the high operating cost. If steam engines were used it would be better to couple them directly to the mill, providing the steam line were not too long. If a large station with a capacity of 10,000 to 20,000 h.p. is available the variations in load will not be of so much importance, as the percentage of overload caused by the variation of power required in the mill will be much less.

Reversing Mills. — "In reversing mills the load varies still more than in those provided with a fly-wheel, and for such it would probably be impossible to dispense with the transformer. In recent years comparisons have often been made between such mills

and the large hoisting engines used in mines. This comparison may easily lead to wrong conclusions, owing to the fact that in the two cases the effects of the moving mass are totally different. The inertia of this mass is, in the case of the hoisting engine, of supreme importance, as the cages, ropes, drums, and counterweights of a mine hoist for $4\frac{1}{2}$ tons net load will weigh in the neighborhood of 90 or 100 tons. The whole is brought quickly to its maximum speed, and after maintaining this for a short time it is as quickly brought to a standstill. The total friction, that of the journals and that due to the inflexibility of the cable, is comparatively small, and in order to stop the machine it is not sufficient simply to shut off the power, but an effective brake must also be used. It is, therefore, in this case perfectly correct to brake electrically, storing up the energy generated by means of a fly-wheel transformer in order to utilize it subsequently.

"Such a storage of power is, however, useless in a reversing mill, which has comparatively such small moving parts that their inertia is negligible. This will be seen at once by comparison of the weights of the rolls, couplings, pinions, etc., and the distance from their axis of rotation with the size of the numerous friction surfaces. As a result, when the power is cut off, the mill will come to a standstill almost immediately, so that it is only necessary to equalize the variations in load between zero and the maximum, for which purpose a fly-wheel transformer could be used. Here again the question arises, however, whether the power station is of sufficient capacity and whether it is driven by gas engines using blast-furnace gas. If the latter is the case the gas should not, as electricians often assert, be figured as a waste product, but charged to the mill at its heat value, for in most plants steam is used for one purpose or another, and this, if sufficient gas is not available, must be generated by means of coal. An electric power station with fly-wheel transformer and all accessories would probably cost twice or three times as much as a complete plant for direct driving by means of a steam engine.

Reversing Engines not so Wasteful as Supposed. — "Reversing engines are not nearly so wasteful as is often supposed, the consumption of steam being, in many cases, lower than that of a compound condensing fly-wheel engine of the same size. This is due to the fact that such an engine never runs when the mill is idle, which would not be the case with electric driving, as the

power station would hardly be stopped for a shut-down of ten or fifteen minutes or even half an hour. With a power station driven by steam engines it is unlikely that the electric operation of reversing mills would pay, however economically the engines in the power house might work. For ordinary three-high mills a transformer is generally unnecessary, variations in load as high as 25 per cent. being easily taken care of in the power house by an increase of speed at most of 2 to 3 per cent.

"The question now arises whether there is any economy in driving rolling mills electrically. As stated, the necessary plant, including the power house, is very costly. It would probably be found that with a simple installation, without transformer or secondary battery, with a power house driven by gas engines, figuring a loss of energy due to the electric transmission of at least 20 per cent. and including interest and depreciation, the total operating cost will be somewhat less than that of the steam engine.

Comparative Figures of Steam and Electric Installations. — "To illustrate the costliness of installing a power station and transformer some figures are given which were obtained to ascertain the relative advantages of a steam hoisting engine as against an electric installation for the same purpose. The power was to be obtained from an existing power house, and boilers were available either for a steam engine or for electric generators. The cost of the steam engine, including foundations and buildings, was estimated at $22,500, while for the electric hoist with direct-current alternating-current transformer the average of various bids was $40,000. If the cost of the power station, which may be set at $25,000, is added to this, it will be seen that the total is far more than double that of the steam installation. The figures show that the increased charges for interest and depreciation more than offset the saving in fuel and make the cost of operating much more expensive with electric than with steam power. It is probable that the same result would be obtained if similar estimates were made for a reversing mill, and that, in spite of the use of gas engines in the power house, direct driving by a steam engine would prove the more economical.

Advantages of Using Electricity. — "The advantages of using electricity are the greater security of operation and the possibility of dividing the gas-engine installation into smaller units in

the power house than is possible for direct driving, in which case the gas engine must necessarily be of sufficient size to run the mill. It is no doubt advantageous to drive small mills, requiring 250 to 500 h.p., electrically, if a suitable power house is available, but for larger trains the case is different.

"In many cases where gas engines have been installed for driving mills trouble has been caused by the engine being too small for the work which it is to perform. The point has in many cases been overlooked that the gas engine's nominal power is its maximum, while with a steam engine its nominal power may be exceeded by 50 per cent. or even more. A mill gas engine should have a large reserve of power, so that it may cope with steel insufficiently heated, with a greater output of the mill, or with other factors causing an increase in the power required.

"Another point which has often led to too small an engine being installed is that the quality of blast-furnace gas is very variable. It is generally stated that such gas has a heating value of 900 or even 950 calories. It is true that such a gas is often made, and sometimes one that is richer, but it is equally true that the heating value may be only 800 and as low as 750 calories. If an engine is working under its full load, which it is designed to carry with 900-unit gas, it is clear that it will not be able to do the work if the value of the gas falls as low as indicated above. Recent reports show that gas engines driving mills directly are giving better satisfaction than is often supposed, many of the troubles which were at first experienced having been overcome. Finally it may be stated that it is advisable to use duplex engines with a large excess of power for rolling mills. It is then possible, if one side of the engine needs repairs, to operate the mill at least partially with the other side. By this means a certain amount of reserve is acquired."

H. WILD

H. Wild confirms Mr. Ortmann's conclusions that only in the case of small mills is there any assurance of profit in electric driving, while for large units the charges for interest, etc., will eat up anything saved in other directions. He considers gas engines using blast-furnace gas very suitable for rolling mills and has reached the conclusion that they should have 1.8 times the power of a steam engine for the same purpose. If the blast

furnaces are situated any distance from the mill the gas might be compressed at its source, in order to reduce the size and cost of piping, and the installation of a gas holder is advisable in order that the mill may not too quickly be affected by trouble at the furnaces. A gas engine will not pay when the gas for it is produced specially and the installation replaces an existing steam engine, for it is not capable of saving in fuel the interest charges on the new plant and the old.

F. WEIDENEDER

It is interesting to compare the views of these two practical mill men with those of F. Weideneder, who compares the relative cost of driving reversing mills electrically and by means of steam engines, both with and without the use of exhaust turbines. He states that the General Electric Company of Berlin has an order for three installations for electrically driving reversing mills, each for a maximum load of 9000 h.p. They will be constructed on the same principle as electric mine hoists, the variations in load being balanced by a fly-wheel. To quote:

"The rolls are coupled either directly or by means of gearing to the direct-current motor. For blooming mills with an average of 60 to 65 r.p.m. the use of gearing will be avoided. An unfavorable position of cranks, as happens with a steam engine, does not have to be taken into account, and a motor of the power in question will not be particularly expensive even at this low speed. In order that the power station may not be affected by the sudden variations in load, and to avoid the loss of energy in resistances, a transformer is installed near the mill. This consists of a direct-current dynamo, which is coupled directly to an alternating-current motor on one side and a 50-ton fly-wheel on the other. The motor is connected with the central station circuit. When running light the speed of this transformer is 365 r.p.m. In order to make use of the inertia of the fly-wheel, however, the speed must decrease as the loss increases and *vice versa*. This is affected automatically by increasing the resistance in the armature as the load increases; this causes but slight loss of power. A maximum decrease in speed of 20 per cent. is sufficient for large reversing mills.

"As regards size, the dynamo should be designed for the maximum load of 9000 h.p., the alternating-current motor for the

average load of 2000 h.p. The field current for the dynamo and the mill motor is generated by a transformer, consisting of a 30-kw. direct-current dynamo coupled directly to an alternating-current motor of corresponding size.

"Up to 65 r.p.m. the speed is controlled by means of the current of the transformer dynamo on which it is dependent, so that it is easy to stop or brake the mill motor by reducing this current down to zero. During this braking period the inertia of the moving parts is converted into useful energy and stored up by increasing the speed of the fly-wheel. In the final passes a higher speed is required, and this, from 65 to 90 r.p.m., is attained by weakening the field of the driving motor. The fact that so doing decreases the turning moment is not disadvantageous, as less power is required than in the earlier passes."

Detailed figures are given to show the relative first cost and cost of operating of an electric installation and steam installation, both with and without exhaust turbines. Owing to the totally different conditions these figures are of little value in this country, however correct they may be in the land of their origin, but a statement of the final results arrived at may prove interesting, as follows:

Annual Interest, Depreciation and Operating Cost

1. Steam engine with exhaust turbine	$104,500
2. Steam engine without exhaust turbine	121,100
3. Electric drive	63,800

In all cases it is assumed that the steam is generated in coal-fired boilers and that the average load is 2000 horse-power.

CARL ILGNER

"Roll trains are classed in three categories, according to the manner in which the power for driving them is utilized. The classification is: 1. Reversing mills. 2. Trains always running in the same direction, but at a speed varying from time to time in the ratio of 3 to 2, while the slowest speed corresponds with the greatest absorption of power. 3. Those in which both power and speed are constant.

"For the first of these classes the gas engine is inapplicable, notwithstanding the attempts made at various works to intro-

duce a reversible coupling between the fly-wheel and the roll train. Electric driving affords excellent means not only for easily and certainly regulating the speed, but also for transforming the variable power required by the roll train into one that is almost uniform, in which case there is no doubt of the success of electric driving. Several electric roll trains are under construction, and the preliminary trials hold out the hope of thorough success.

"If a roll train, the speed of which varies periodically, be coupled with a gas engine, the latter will furnish the greatest amount of power when the speed is lowest. But the products rolled at this slight speed constitute only a third of the whole output, while the remaining two-thirds will be rolled at the maximum speed of the gas engine, the efficiency of which will be very slight. It follows that the gas engine will give out a considerable portion of its power while consuming too much gas per horse-power-hour. By employing electricity as an intermediary, the variations of speed are transferred to it so that variation of the load on the motor is diminished. The consequence is that, notwithstanding loss in the electric transmission, and without regard to variation in the speed, gas engines that are no more powerful than those for driving the roll directly may be erected at the generating station.

"It is perfectly evident that reversing mills and cogging trains absorb a widely varying amount of power. Electric driving and centralizing the generation of energy present excellent means for regulating motive power, on the one hand by increasing the rotary masses in motion, to which are added those of the fly-wheels at the generating station, and on the other by distributing the shocks and the irregularities over the whole generating station. It is evident that the power thus required by the cogging rolls from the gas engines at the central station will be less than that which the rolls would absorb if each were driven directly by its own motor.

"As regards the third class, — roll trains of constant speed, which are generally used for plates and small bars, — variations of load are not considerable, and in their case electric driving does not afford any great advantage. If, however, it be required to drive roll trains of all three classes, there is no doubt that centralization of the power is preferable to the use of a gas engine for each separate roll train. And to the advantages already claimed for the electric driving of roll trains in classes 1 and 2

must be added those resulting from centralization of the power. The total power absorbed by all the roll trains at a given moment is undoubtedly far less than the sum of the maximum power required by each train.

"Another advantage is that the motor of the generating station can receive all the care it requires, because one can be kept in reserve. If the gas engine be coupled directly with the roll train, the stoppages required for overhauling will not be compatible with the proper working of the train. The electric motor stands overloading better than does the gas engine, while it can be replaced by another of greater power more easily and at less expense. The provision of a reserve for meeting hitches at the blast furnaces or coke ovens is easier at a central station than for each motor.

"In short, a whole series of weighty considerations counts in favor of centralization. If it be considered that at the central station much less power plant will need to be laid down, while larger motors may be employed, and if again the connections of each train and the long gas pipes be considered, the conclusion is warranted that the first cost will not be an obstacle to adopting the principle of central electric stations. The difficulties encountered in the progressive transformation of works must not be disregarded, but it appears undeniable that centralizing the motive power of rolling mills, with electric driving and the use of blast-furnace or coke-oven gas, gives promise of great economy as compared with present practice."

AUTHOR'S CONCLUSION

While there is still some divergence of opinion existing as to the special equipment to be adopted, the above discussion reveals one thing beyond doubt, namely, that gas engines as at present constructed are not so well fitted for direct driving of roll trains, as they are for application in the central station. In steel works where a short stoppage of one roll is of no great consequence, because the material may in the meantime be finished in some other department, or because it is easy to recover the loss of production in some other way, there direct drive can be recommended. But where mills are to do continuous service and cost of equipment is not a limiting factor, there electric drive with gas

engines in the central station will prove the most economical of all. The fact that in Germany one-eighth of the total rolling service in the iron industry is now rendered by electricity proves better than can any technical argumentation that our energies must in future be all concentrated in the one direction. This much is also certain, that the initial cost of equipment is considerably higher with electric than with direct steam drive, and also that the floor space required is larger. In order to secure any profits from the change to complete electric centralization, the higher cost of equipment must be compensated by the lower cost of operation and up-keep. Consequently the expenditures for power service must be reduced to the lowest commercial figure, which is possible only when realizing great savings in plant fuel cost. This again can be accomplished only by covering all demands from the cheapest source available, namely, the waste gases, and by husbanding these so well as to preclude entirely the employment of costly boiler coal and, in addition, gaining some revenues from the sale of surplus power to outside consumers. So we find at last that gas-engine drive in the central station is a logical necessity to enable electrification of rolling service, and thereby the attainment of maximum industrial economy within the works.

Blowing Service

The department of blowing is one which has been opened to gas power in all German and in many other European works. It does not require much reasoning to become convinced that an engine which serves to deliver to the blast furnace the air that is required in the smelting process will give highest all-round efficiency when operating directly on the gases which are generated through the combustion of the coke in the furnace. Since the peculiarities of blowing service are in the main of such nature as to affect the design, construction, and operation of the gas prime mover proper, the arising modifications are considered in the chapter referring to that special subject. So I shall here complete my former remarks in another direction.

Metallurgical engineers not familiar with European achievements often exhibit ignorance as to the question: What reserves are available for a blast furnace which has shown signs of weakness and must be closed down, thereby depriving the power

section of the plant of a certain contribution or quantity of gas, which is indispensable for fulfilling all internal and external obligations that have been undertaken by the works management? It would be wrong to conclude that, owing to the remote possibility of having to close down one or the other furnace for repairing, the surplus gas emanating from it should not be utilized at all, except for covering the requirements at the furnace proper. On the contrary, in Europe engineers are endeavoring to reduce the unavoidable losses and the demand at the furnace (namely, leakage at furnace top, gas used for blowing and for heating the blast) to the lowest possible amount in order to reserve the rest for more profitable usage.

Considering the case that in a plant of four furnaces which all contribute their share to the power station, one is beginning to show signs of distress and must be shut down, then one-fourth of the total quantity of gas required is no longer generated. Of this amount only one-half must be replaced by suitable means, since almost 50 per cent. of the total of one furnace is used for operations at that blast furnace proper, and can be dispensed with when the furnace is not working.

As for the rest it is, of course, unnecessary to replace the total quantity of gas so long as we have sources of generation available which can deliver the same amount of kinetic gas energy to the power plant. This reserve energy can be derived either from gas producers or from coke ovens which in combined plants are always available. Even with steam-driven blowing engines such as are employed almost exclusively in American practice, it has been commended to provide for some means, beside blast-furnace gas, for supplying additional power or blast at need.

The best equipment which can be provided for such cases of emergency consists of a bank of gas producers which can deliver a regulable quantity of rich gas to the boiler plant where it can be burnt together with the blast-furnace gas under perfect control, instead of using additional boiler coal. Where these wise precautions are taken the breaking down of one furnace would initiate no appreciable amount of trouble and no interruption in the power service at all, since the rich producer gas can be made to fully replace the loss of poor blast-furnace gas. It is known that producers when properly constructed and subdivided can be

overloaded by 100 per cent. and more, if the necessity should arise; also that they can be put in operation from cold within very few minutes, and that they can be fired with inferior grades of coal, mine culm, etc., of which there are enormous quantities available in every large plant.

Since of the three available sources of gas generation, the blast furnace, the coke oven, and the producer, none is worked at its utmost capacity under normal conditions, it is quite easy to provide for the required gas energy from the combined equipment, and without having any special reserves. Where blast furnaces are the only source of power, the provision of spare producers is commendable both for securing greater regularity of product and for having sufficient reserve for use in the central station.

The electric canalization of industrial districts and the system of power exchange which is now so widely adopted in large-scale operations in Europe will tend further to secure stability of production, independent of local breakdowns.

The Cleaning of Blast-furnace Gas

increasing fuel consumption of furnaces

Besides the ever active element of foreign competition which forces the ironmasters of every progressive country to unceasing new efforts, the American iron industry has had another growing factor to contend with in recent years, and one that calls more imperatively than any outside influence for a reduction of waste; namely, the ever increasing consumption of fuel in the blast furnace. While in 1880, in the best practice, the amount of coke required for the production of 1 ton of pig iron remained within the moderate limits of 1760 to 1870 lb., it is interesting to observe that this condition has been considerably shifted within the last 25 years, since, according to recent reports, from 2420 to 2530 lb. — that is, nearly 300 lb. over 1 gross ton of coke — has to be expended per ton of pig iron in the blast furnace, and it is quite likely that this quantity will even be increased in future operations.

The reasons therefor are found to rest mainly with the declining quality of the ores, the metallic contents of which are inferior by nearly 10 per cent. to former values. At the same time the

quality of the coke has noticeably decreased, but it is hoped that the growing introduction of retort coke ovens and the utilization of by-products now almost universally adopted in Europe will eventually overcome this defect. The mechanical distributing and charging devices, which serve to feed the ore and the fuel to the blast furnace, have also introduced new difficulties and losses, which up to this date have not yet been successfully corrected.

It is obvious that these deficiencies and their influence on fuel consumption, and therefore on the cost of pig-iron production, will be the more felt the farther an iron-smelting plant is located from the coal districts, and the more the factor of transportation, with its accompanying considerations of freight-car rates, car famine, and other incidentals, enters the problem.

IMPROVEMENTS NOW BEING MADE

As was said before, all these causes have contributed to direct the attention of American iron masters more toward the adoption of modern methods of production. The introduction of the Gayley system of dry-air blast and of various improvements in the manner of automatic ore feed are visible indications to that effect. Since the return of the committee which was sent out by the United States Steel Corporation to study the application of gas power in the European iron industry, and on the basis of its favorable report, much headway has also been made in the utilization of waste blast-furnace gases for operating blowing engines and engines for driving rolling mills and central stations; this practice is by far the most important of all methods that are available for decreasing the cost of production, on account of the enormous savings that can be effected. This is shown in the chapter on "Gas Power Economics," wherein the actual results from various continental gas-driven iron-smelting plants prove to effect a net reduction of operating cost of about two-thirds against what was originally obtained when steam power was employed.

THE CLEANING OF GAS ESSENTIAL

It is the object of this chapter to study in detail an interesting and important feature of gas-power application, namely, the cleaning of the power gas, which unfortunately has not received

in this country the attention which it deserves, yet which is as essential for the continuous and economical working of a gas-power plant as are the elaboration and standardization of modern methods of engine design, of which I have treated on another occasion.

While the advocates of gas power are very apt to refer to the thermal inferiority of the steam engine whenever they compare the commercial prospects of respective installations, they never stop to point out the superior qualities of steam as an energy-transforming medium. Nor do they try to realize or learn from the experience gained through the employment of such a perfect working fluid in the prime mover, nor to adopt those fundamental principles and improvements which in the evolution of steam-power plants have now become absolutely indispensable and standard features. Even though steam is an ideal working fluid of fixed physical and chemical properties, which have now been accurately determined by scientific theoretical and experimental investigations, within the commercial temperature limits, it has proved an absolute necessity to provide for efficient means of guarding against boiler scale, of eliminating impurities contained in the feed water, of supplying dry steam to the engine cylinder by extracting the water and preventing condensation, of separating the oil from the steam, etc., and no engineer would regard a modern steam plant as up to date and complete which lacks these purifying and cleaning devices and which are a necessary addition to the plant, no matter how perfect the boiler and how efficient the engine.

COMPLEXITY OF THE GAS PROBLEM

In the working process of gas-power plants, which is characterized by the direct transformation of gas into work without the intervention of the comparatively inefficient boiler equipment, we employ a working medium that is produced by a very complex process of gasification either in the blast furnace, the coke oven, or the ordinary producer, and from various fuels. This gas when generated changes its composition, temperature, and volume according to the manner of feed, the quality of fuel, the degree of moisture supplied with the air, the kind of load and other influences. It also carries with it from the source of gen-

eration to the place of utilization a considerable quantity of dust, water vapor, tar, sulphur, and other impurities, which further complicate the nature of the medium and the process of its transformation into power. Besides all this, it is necessary to admit for every condition of load and for every individual position of the governor a certain quantity of air to the gas, which varies its temperature and composition with the atmospheric conditions of the season, and its density with the altitude of the respective location. For it is only thus that we can secure a corresponding invariable equivalent of work produced, no matter how often or how long this position is occupied. Nor is this uncertainty of operation concluded in the engine proper, as such a constantly changing mixture of gas and air and their unstable and other constituents has to be ignited in the cylinder, and it is known that the rapidity of flame propagation, inflammation, and combustion is again dependent on composition, calorific value, temperature and compression of the charge, and also on the condition, energy, and efficiency of the electric sparking device and other items which it is of no value here to consider.

Finally, while steam as a working fluid retains during the utilization process its chemical properties and only changes its physical relations of temperature and pressure, the gaseous mixture of internal-combustion engines undergoes during the process of energy transformation in the cylinder a complete change of both its physical and chemical properties, such change increasing the number of solid and gaseous by-products and impurities contained in the working fluid.

A FREQUENT CAUSE OF BREAKDOWN

With all these facts in mind it is surprising to see the attitude of indifference and negligence with which both manufacturers of gas producers and engines, as well as the consumers of gas power, continue to treat the question of gas cleaning, which, of all the various factors considered as complicating the problem of utilizing gaseous fuels by internal combustion in engines, is the only one that we can positively master by adopting scientific and efficient methods of purification. This attitude of the trade cannot possibly be based on ignorance of the actual conditions, as these have been demonstrated time and again by serious breakdowns

which, though frequently occurring, are never — and for obvious reasons — revealed to the eyes of the buying public. Nor do the power-consuming circles take pains, through impartial and expert investigation, to ascertain the actual state of affairs and the origin of the failure. The gas-engine manufacturer when questioned for the reasons of the breakdown will shift the responsibility on the shoulders of the producer-maker, and the latter will invariably decry the character of the engine, because it cannot without serious troubles digest the dirt which the producers supply together with the gas. Both fail to inform their clients, when inquiring for details on the respective apparatus, that in addition to buying producers and engines it will be necessary to invest in an efficient cleaning plant, which is indeed the only real safeguard and guarantee they can get that the prospective gas-power plant will do the required work continuously. A similar condition of things holds true in blast-furnace and coke-oven practice, and in every single instance of a breakdown of this kind the power consumer has yet had to pay the bill.

This is a deplorable state of affairs, and one that cannot be too severely criticized, since it has cost the American gas-engine industry already a good part of its prestige, and has seriously hampered more universal progress by undermining the confidence of the purchasing public in the reliability and economy of this modern form of power generation.

THE LACKAWANNA GAS-ENGINE INSTALLATION

We have only to study the results effected by inefficient methods of gas cleaning in some cases taken from actual practice, and which have been confirmed by the experience of several years, in order to become convinced that we must devote more careful attention to this feature. What is regarded as one of the largest gas-power plants, and certainly the most remarkable of its kind in this country, is the 40,000-h.p. gas-engine installation at the works of the Lackawanna Steel Company, Buffalo, N. Y., where the available blast-furnace gas is utilized for driving both the blowing engines, which serve to compress the air that is afterward used in the reduction process of the blast furnace, and the three-phase current generators in the electric central station, operating in parallel. The engine part of this plant has

been described in the technical press, so that it is hardly necessary to be discussed again at this time. What interests us most is the gas-cleaning plant which is shown in the accompanying illustration.

The provisions which were originally made for purifying the gas when the engine plant was first put in operation were very poor, indeed absolutely inadequate, as there was at that time a current belief among gas-power engineers that the scrubbing difficulty was a mere imagination, and that the fine silicious or other dust with which the gas was laden would readily and without trouble go through the engine, especially if the latter was of the Körting two-cycle type, having no exhaust valves to contend with and where all foreign matter is supposed to be expelled through the exhaust ports. As a matter of fact, there was until very recently little actual experience available on this question, and also on systems of cooling and washing the gas, at least not for plants of such magnitude and for ore of the composition used at the Lackawanna plant. Experience has now proved that the treatment of the dust problem is entirely dependent on the quality of the ore which is being smelted, and so it was found necessary afterward to install an additional gas-cleaning plant.

THE LAYOUT OF THE CLEANING PLANT

The gas generated from two blast furnaces is sent to a common cleaning plant located between them. Eight water-spraying towers of the Körting system, together with eight centrifugal hydraulic fans working with water injection and arranged in groups of four, serve to carry out the three processes which are essential for purification, namely, the cooling, washing, and moving of the gas. Fig. 127 shows the larger of the two plants which handles the gas of two blast furnaces of 700 tons daily capacity each. The gas is taken off at three points of the furnace top and conducted through a vertical down-draft pipe to the dry-dust catcher *A*, which is supposed to act through the retarding effect of its large volume on the speed of the gas flowing through, thereby allowing the solid particles of the dust to separate from the gaseous molecules by gravity. A certain quantity of the gas generated in the blast furnaces is required for heating the hot-blast stoves *B*, which serve to preheat the air that is used

in the reduction process of the furnace, such quantity varying from 25 to 30 per cent. of the total, according to the degree of purity of the gas, the construction of the stoves, and the condi-

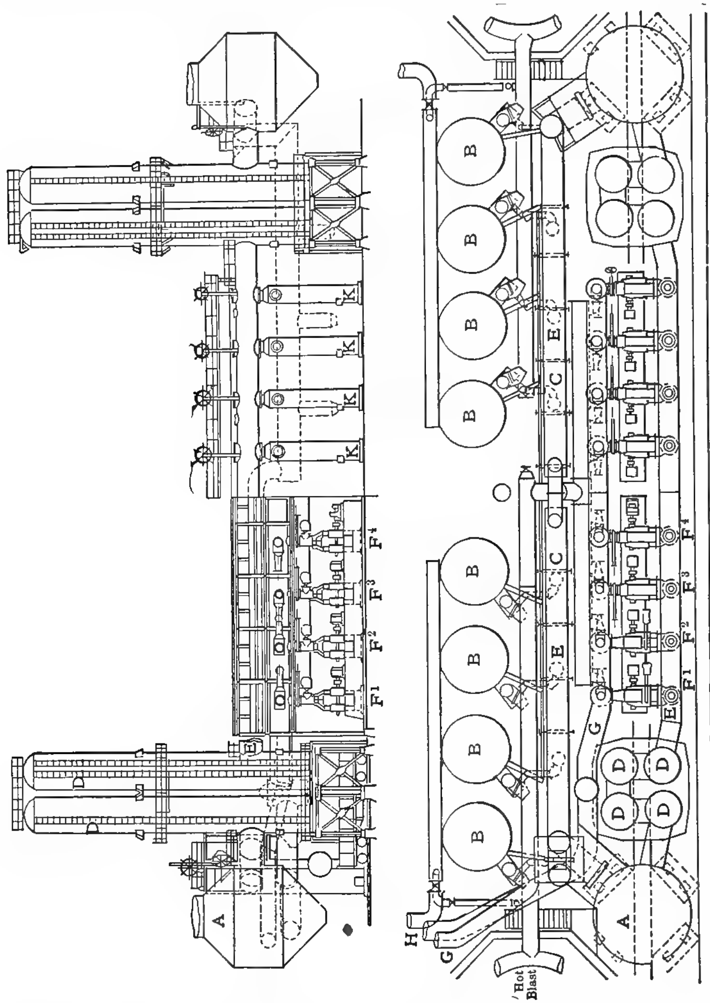


FIG. 127. — Elevation and Plan of the Gas Cleaning Plant of the Lackawanna Steel Company for its Large Furnaces.

tions of operation of the blast-furnace plant in general. In the plant under discussion this portion of the gas goes directly to the hot-blast stoves without being subjected to any kind of treatment, so that almost the whole quantity of dust is carried with the gas

into the stoves, where it settles down and accumulates in the flues, thereby necessitating a considerable expenditure of manual labor every few days for its removal, besides detracting greatly from the heating qualities of the gas. Practically the only provisions made to arrest the dust on its way to the hot-blast stoves consist of eight stump pipes *C* branched to the main *E*, which the gas on its way to the stoves has to pass. Thus by changing the direction of flow it gives off some more of the dust, which may be removed through cleaning doors at the bottom of pipes *C*, while the large particles of ore, limestone and coke in the gas are precipitated by gravity into the pockets of the flues, the fine and impalpable dust remains suspended in the gas-like smoke in the atmosphere, and can only be removed by washing or filtering through some medium which allows the gas to pass and retains the solid matter.

COOLING TOWERS AND HYDRAULIC FANS

The rest of the gas, including that portion which is used under boilers for raising steam, is subjected to a more efficient cleaning process by passing it in succession through the cooling towers *D*, of which there are two groups of four towers each, one for each furnace, as shown in Fig. 127, and which are equipped with Körting spraying nozzles and have shelves arranged, forming successive compartments which the gas has to pass, thus becoming enriched and saturated with water vapor. This mixture of gas, water vapor, dust, and steam is then sucked through the main *E* to the two groups of hydraulic fans *F*, which are arranged in parallel, but can also be thrown in series if desired.

In these hydraulic fans, which are of the Buffalo Forge Company's make and are of the standard type, having nozzles through which a certain constant quantity of water is injected, the gas mixture is again profusely sprayed with water. Through the centrifugal action of the fan blades the whole mass of gas, steam, water spray, and dust is vehemently whirled around, mixed and thrown outwardly toward the delivery side, where it dashes against the fan casing. There is really no time for the separation of the various constituents by gravity or centrifugal force, and it is only that portion of the dust which is absorbed by the liquid water that is actually eliminated from the gas and drained off together with the water at the bottom of the fan casing.

Without trying to construct a speculative theory on the working process that is going on in these hydraulic fan washers, it may be said that their efficiency is low, first, on account of the high temperature of the gas, which counteracts the condensation

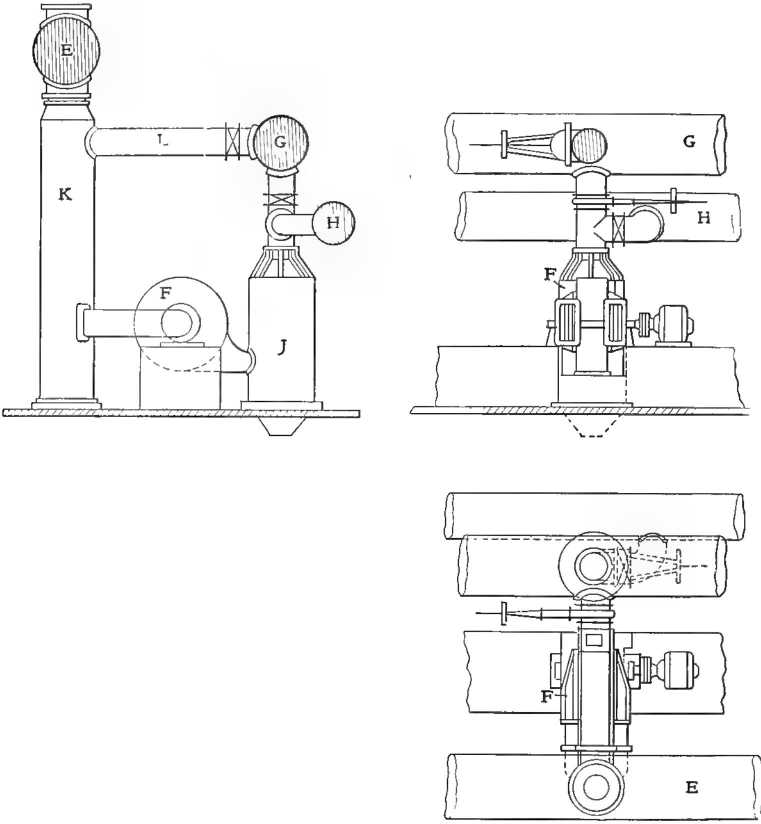


Fig. 128. — Detail Arrangement of Centrifugal Fan Washers.

of the suspended water vapor, and second, because the duration of enforced contact between liquid and dust — which is effected on the cylindrical walls of the fan casing — is entirely too short to allow of a thorough absorption of the solid particles by the liquid fluid. Such process can only be executed with a reasonable degree of efficiency, or, in other words, a fair degree of purity of the gas can be attained by arranging several fans, at least

three, in series, so that the gas mixture has to pass through all of these in succession, thereby finding time for gradually cooling down. The cycle of action in such combinations and their deficiencies as regards floor space, water consumption, and power required will be discussed later.

After passing through these washers the surplus gas which, of course, has suffered considerable contraction on account of the cooling process, is discharged into two different mains, *G* and *H*, of which the first leads to the boilers, the other to the gas-engine plant. As can be seen in Fig. 127 all pipings of the gas-cleaning plant connect symmetrically to both furnaces in order that the single apparatus may be shut down and by-passed for purposes of cleaning or repairs, without thereby impairing to

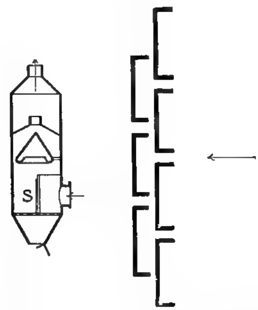


Fig. 129. — Details of Scrubber.

a great extent the regular and uniform working of the furnace plant. The fans *F* are connected to the gas-conducting pipe as shown in Fig. 128, which gives a front elevation, plan and side elevation of the particular part under discussion. Each fan has a separate inlet pipe coming down from the common gas main, which can be closed by a valve. From the fans the gas proceeds to a dry scrubber *J*, the inner construction of which is shown in Fig. 129. The gas entering the scrubber first dashes against the walls, built of vertical channel beams, which are superimposed as shown in Fig. 129 in detail, and which serve to retain the major part of the water and dust. Two reversed funnels placed in the upper part of the scrubber are to complete further the drying process. There is another connection made between the vertical downcomers *K* and the dry scrubber *J* through pipe *L* and valves, which allows the by-passing of the

gas around the fan if so desired. All gate valves employed in the cleaning system are of 36-in. size except the valves of the fans F^1 and F^2, which are 42 in. Three-phase current motors are used to drive all fans except F^4, which is driven by a direct-current motor.

Figure 130 shows the cleaning plant for the gas coming from the two 300-ton furnaces, which differs from the other plant in

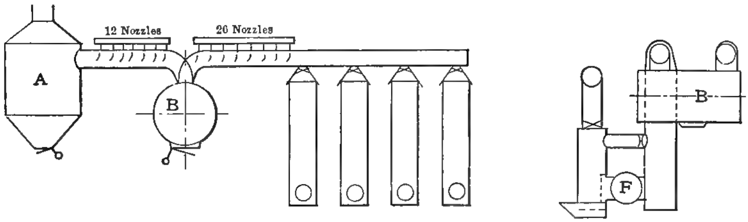


FIG. 130. — Design of Gas Cleaning Plant for the Small Furnaces.

so far as employing no separate cooling towers. The gas coming from the dust catcher *A* is cooled by 12 water-spraying nozzles in the overflow pipe, whence it enters the large settling chamber *B*. On its way to the vertical downcomers it is further washed by 26 water-spraying nozzles in the horizontal pipe and then proceeds to the fans, whence it is distributed to boilers and gas engines, respectively, in the manner described.

PURITY OF THE CLEANED GAS AT LACKAWANNA PLANT

According to an official statement made by the Lackawanna staff some time ago, the degree of purity of the gas that can be reached with this cleaning plant was shown by its contents of from 0.043 to 0.934 g. (0.663 to 0.524 grain) of dust per cubic meter (35,314 cubic feet).

It is interesting to observe how often and how widely practical results differ from theoretical assumptions since at a recent expert investigation made by Professor Lucke of Columbia University on the plant under discussion, to determine the origin of the various troubles that were experienced in the operation of the Lackawanna gas engines, the alarming fact was revealed that in the course of one month's time as much as 10 lb. of solid dust had settled down on the inlet valves of the engines, leaving aside the quantity that accumulates in other parts of the combustion chamber and inlet pipes.

Notwithstanding this extraordinary condition and other difficulties presented in the particular case referred to, the engines kept running quite satisfactorily, which is an extraordinary and unique performance under the conditions outlined. It was also confirmed that the frequent breakdowns that were encountered, as, for instance, the cracking of cylinder heads, of which one had to be replaced in the plant every month on the average, were due not to deficiencies in the engine system — of which several thousand horse-power do continuous service in continental iron works — but primarily to the employment of inferior materials and methods of casting, so that it is safe to say that no other prime mover would stand similar bad treatment and similar severe stresses as does the gas-engine plant in question.

Reference to this is made to show that the criticisms of gas-engine opponents are absolutely ill founded when directed against the working process or the constructive principles of the internal-combustion engine as a prime mover, but that they are entirely justified in decrying the negligent attitude of the manufacturers of gas engines and appliances toward the all-important question of gas cleaning. No matter how well constructed a power plant may be, nor how elaborate the design of the prime movers employed, it must invariably suffer from breakdowns if we fail to subject the working medium to a thorough treatment of purification before allowing it to enter the engine, regardless of whether steam, water, or gas be employed.

ELEMENTS OF COST TO BE CONSIDERED

Regardless of what are the commercial objects, the constructive principles, and the modes of action of a mechanical device, whether it be the transformation of kinetic fuel energy into some form of available power, or the conversion of raw materials into refined products, or the cleaning of matter to some standard of purity, the complete problem of adjusting the conditions, so far as physically possible, of any plant, machine, or apparatus that requires the expenditure of energy, material, and space for the realization of maximum industrial economy, must take into account: (1) Cost of fuel to obtain the heat flux or heat generation along with other accompanying working expenses; (2) cost of bulk and weight of the apparatus; (3) cost of high stress, and (4), profitableness of high speed.

In view of the above requirements it is interesting to observe that in the course of development of gas-cleaning plants the original bulky forms of apparatus, such as air-cooling and water-spraying towers, wet scrubbers, etc., have been replaced, to a large extent, by mechanically operated high-speed revolving fans and similar appliances, which, regarding first cost, floor space, water consumption, and labor required, are greatly superior to the earlier forms. We shall later see what has been the effect, expressed in numeric values, on the cost of installation and operation. But before taking up the question of economy it may be well to discuss the various means which have hitherto been proposed for the execution of the process, and preceding this we shall have to make clear what we expect to perform with such means.

TEMPERATURE, PURITY, AND DRYNESS OF THE GAS

To secure maximum efficiency of combustion we must have a cool, clean, and dry gas. But these requirements vary in degree according to the manner and kind of application. For use in hot-blast stoves and under boilers the temperature of the gas may be higher than for use in gas engines. But higher temperatures enable the gas to contain a large amount of moisture, which is again harmful to the all-round efficiency, as will later be shown. The degree of purity of the gas for heating furnaces need not necessarily be higher than 0.5 g. of dust per 1 cu. m., or 0.2 grain per cubic foot, as it is found that the firebrick lining of the ovens is apt to fuse when still higher temperatures are maintained. For use in engines there are no lower limits fixed for temperature or purity, but the upper limits are the more rigidly drawn, namely: Temperature, 25 deg. C. and degree of purity 0.02 g. per cubic meter, or 0.001 grain per cubic foot. The latter figure is the basis on which German manufacturers give their guarantees on gas engines. This covers the case as far as temperature and purity for various purposes are concerned.

It must be remembered that even a very small amount of dust is prohibitive in gas engine cylinders as it, naturally gritty, will unite with the lubricating oil, forming a pasty mass which produces an abrasive effect only excelled by oil and emery. As 75% of the dust is metallic oxide, it, when subjected to a temperature of 300 deg. F. (the heat of inflam-

mation), will be precipitated as iron and steel. The third requirement to be considered is freedom from excessive moisture. When the gas leaves the furnace (we are now speaking of blast-furnace gas) it is laden with dust, containing 8 to 15 g. per cubic meter (4 to 7 grains per cubic foot) and other negligible impurities, and is very hot (140 to 180 deg. C.) but comparatively dry. The greater part of the dust is first removed by a dry process in the dust catcher, while the finer particles are eliminated by bringing the gas in intimate contact with water. Now this water, leaving aside its varying temperature, represents in all processes an almost constant amount compared to the quantity, temperature, and composition of the gas and its dust contents, all of which vary according to the course of the smelting process and the condition of the season. This water remains suspended in the gas after leaving the scrubbers, washers, and fans, and to secure regular and efficient combustion it must be removed again down to a very low percentage before being conveyed to heaters and engines.

DRY GAS A LOGICAL SUPPLEMENT TO THE DRY-AIR BLAST

I here wish to call particular attention to the fact that the same considerations which seem to favor the introduction of the Gayley dry-air blast process for furnace work commend even more emphatically the employment of dry gas for heating stoves, boilers, furnaces, and engines. It is indeed an absolute necessity to burn and utilize the gas generated in blast furnaces as economically as possible, since otherwise the gain effected in the Gayley system by a reduction of coke consumption (which naturally results also in a decreased output of furnace gas) is outweighed by the additional expenditure for steam and furnace coal, which must be supplied to the works in order to make up for the lesser quantity of gas produced, so that the same total amount of energy may be generated. So in order to do the same work with less gas and to avoid paying additional money for extra steam coal, and to simplify the operation of the plant by employing only one fuel, one working medium, and the most economical type of prime mover, it is necessary to burn the available blast-furnace gas more efficiently than we do now. The more perfect combustion will reduce gas consumption and liberate for

use in other departments a considerable percentage of gas, hitherto wasted. The employment of dry gas is a logical and essential supplement to the dry-air blast process, in order that its commercial benefits may be fully secured.

CLEANING GAS MUST BE ACCOMPANIED BY A COOLING PROCESS

Gas containing a supernormal amount of moisture cannot give high combustion efficiency on account of the deleterious effect of the water globules on ignition and the rapidity of flame propagation, and, further, because of the lower calorific value of the gas per unit volume, of which at high temperatures a considerable part is occupied by the water vapor, and because of the latent heat which is absorbed for heating such water.

It is a well-known phenomenon that 1 cu. m. of gas at 29 deg. C. cannot contain more than 29 g. of water vapor, while at 150 deg. C. it can theoretically contain 2590 g., or, speaking in English units, 1 cu. ft. of space at 70 deg. cannot contain more than 8 grains of water vapor; 1 cu. ft. at 50 deg. not more than 4 grains, and 1 cu. ft. at 32 deg. not more than 2 grains. Therefore the cleaning of the gas from any of its constituents must be accompanied by a process of cooling, as the most perfect and controllable means of drying, regardless of whether the gas is to be used for heat or power purposes. The favorable effects of cooling on the density of the gas as well as on the capacity of the apparatus and the cost of installation have been discussed before. In the Gayley system the blast is cooled while under pressure from the blowing engines by the bosh water. In cleaning gas we have to cool its temperature by direct water injection in order to condense afterward the water vapor that is suspended, as will later be shown.

It is not merely the low calorific value of the gas or the presence of dust which renders the flame liable to be extinguished inside the relatively cool furnace tubes of the Lancashire boiler or the water-tube interspaces of a Babcock & Wilcox boiler, but also the large percentage of moisture. One has tried to overcome this difficulty by burning the gas for steam raising inside a brick-lined chamber separate from the boiler and inside of it. The brickwork then becomes heated to redness and maintains the temperature of combustion desirable for radiating purposes,

but this does not entirely eliminate the thermal inefficiency. The same trouble is experienced in heating blast stoves when the gas leaving the water is not subjected to a thorough process of drying, or else is sufficiently cooled before entering the washer. Nor is it desirable to employ in gas engines gas that is saturated with water vapor. Its calorific value is so low that there is no fear of premature ignition, even when high compression is used. The injection of water into the combustion chamber of gas engines has, in the course of practical development, proved to be an entry at the wrong end of the balance sheet, and it is only when quantity and time of injection are very accurately adjusted to conditions which cannot here be dealt with in detail that the presence of water during compression is of thermal benefit. Generally speaking it is detrimental in that it will prevent ignition from taking place. The same holds true of course of the water that may leak through from the jacket of the cylinder, piston or rod.

THE APPARATUS FOR DRY CLEANING

Coming to the discussion of the apparatus for dry cleaning, of the entire equipment employed in actual practice the dry-dust catcher is all important. Its purpose is to effect a preliminary and rough cleaning of the total mass of gas generated. This is unavoidable regardless of whether scrubbers or slowly rotating washers or high-speed centrifugal washers are employed in the latter part of the process. Its action is that of a combined holder and deflector, being based on the principle of suddenly arresting the motion of a rapidly flowing mass of gas, either by placing plates or other obstacles in the path of travel, so that the gas impinges against their surface, or by changing the direction of flow repeatedly, by arranging consecutive compartments through which the gas is to pass, or finally providing for large spaces where the speed of flow is greatly reduced, thus allowing the dust to settle by gravity. All these means and actions must be combined to absorb the main portion of solid matter which is carried in suspension in the early part of the process.

The employment of corrugated vertical plates along which the gas is made to pass in thin layers with gradually decreasing speed, and in spiral curves, can be recommended as giving highest efficiency. A cone-shaped bottom discharge, built as a

hopper, with cleaning door or valves, must be provided to allow of the removal of dust by manual labor at certain intervals. These discharging devices have to be so designed as to exclude all danger of air entering the dust catcher and pipes or of gas leaking out into the atmosphere, which would disturb the even flow of gas to the main and its composition and might lead to serious explosions; therefore the cleaning doors ought to be arranged so as always to close by automatic action, and they must be conveniently located so as to discharge directly into the dust cart. The dry-dust catcher is an indispensable and very economical apparatus, as it consumes no water, which in some locations is a very serious factor to contend with, no motive power nor practically any floor space, nor is there any appreciable wear. The gas should be taken from several, preferably three, symmetrically distributed points of the furnace top, the discharge pipes combining in one common downcomer, which leads to the dry-dust catcher. For a 100-ton furnace the first cost of a dry-dust catcher is about $5000, in Germany.

While to this first part of the process the whole volume of gas generated must be invariably subjected, its further treatment depends entirely on the use which the particular part of the gas is intended to be put to, and such use, together with the characteristics of the ore, will determine the extent of cleaning and the degree of purity.

SOME CONSIDERATIONS REGARDING WET CLEANING

It has previously been stated that the principle of wet cleaning consists in bringing the gas in intimate contact with water vapor, so that the solid particles of dust are separated from the purely gaseous molecules, which proceed by centrifugal or other action to the discharge main, while the substantial particles of the dust are carried away by the cooling water, which, by some process of filtration, may be cleaned and used over again to reduce consumption.

The earlier forms of water-spraying towers, which were shown in the Lackawanna plant, and which are still in use in some plants on the Continent, do not come up to modern requirements. They are too bulky, consume much floor space and too much water, and to effect a sufficient cleaning several of them have to

be arranged in series, or the gas must be passed, in addition, through several wet coke scrubbers after coming from the spraying towers. One or more fans are necessary to draw the gas through all of this apparatus, and afterward throw out the surplus water particles by centrifugal action. The number of towers, scrubbers, and fans required and the quantity of water consumed, and therefore also the first cost, depend again upon the quality of the ore and the degree of purity of gas desired. With a decreasing value of ores, which in the Lake districts has fallen several points in recent years, the factor of cleaning becomes of course more and more important.

THE COST OF A CLEANING PLANT

Basing our figures on 1000 cu. m. and 1000 cu. ft., respectively, as the unit capacity of a gas-cleaning plant, it is found that the average cost of such plant, including dry scrubbers, per 1000 cu. m., is $916, if the gas is brought to a sufficient degree of purity for heating blast stoves, and $1370 when it is used in gas engines, or $26 and $39, respectively, per 1000 cu. ft. Not included in this price are pipe connections, clearing ponds, water pumps, gas holders, and similar accessories. The average mechanical power required for moving the gas and pumping the cooling water is 5.2 h.p. per 1000 cu. m. of stove gas (0.15 h.p. per 1000 cu. ft.), and 9.7 h.p. per 1000 cu. m. of power gas (0.27 h.p. per 1000 cu. ft.). The consumption of cooling water per 1000 cu. m. of gas per hour is 4 cu. m. for furnace gas, and 6.2 cu. m. for engine gas (31.2 and 46.4 gal. per 1000 cu. ft.), the temperature of the water varying from 5 to 35 deg. C., according to the season. The cost of operation per annum for plants in use 365 days in the year and 24 hours daily, figuring on the horse-power as costing $\frac{1}{4}$ cent, leaving out the value of the blast-furnace gas and neglecting amortization, but including regular attendance, oil consumption, repairs, and up-keep, in German practice, comes out as 5.76 pfennig per 1000 cu. m., or 0.04 cent per 1000 cu. ft. for heating gas, 10.68 pfennig per 1000 cu. m., or 0.072 cent per 1000 cu. ft. for power gas.

Besides this there is an additional expense for occasional cleaning, as the wet scrubbers have to be cleaned every 10 or 14 days, requiring four men to work for four hours. Likewise

the coke scrubbers, to be efficient, must be looked after once a month, cleaned and sometimes filled with fresh coke, requiring four men to work for six hours. This additional expense approximates $20 per year for 1000 cu. m. (35,317 cubic feet).

The above figures are taken from a number of the older continental gas-cleaning plants in iron works, no data being available in this country; they will probably come out somewhat differently on this side of the Atlantic on account of the different cost of material and skilled labor.

RAPID IMPROVEMENTS IN CLEANING PLANTS

The history of modern industry is made in years, while decades were needed up to 50 years ago to mark a decided forward step in evolution. So this type of cleaning plant can even now be reckoned as belonging to the past and having only historical value. The tendency of all branches of modern industry is characterized by the employment of high speed, high pressure, and high efficiency, these features being made possible by the development of high-grade materials and accompanied by a reduction of bulk, weight, first cost, and labor charges; this we can readily see by comparing the results attained with rotary and centrifugal gas-washing apparatus to those of the stationary type, previously described. To cover the subject fully, however, we must first undertake the somewhat dry task of studying the constructive principles and the workings of the various types of rotary washers.

THE BIAN SLOWLY ROTATING WASHER

Of the several forms of rotary gas-cleaning apparatus we may distinguish between two different types, the slowly rotating and the high-speed centrifugal washer. The first form must be credited to Emil Bian, director of the iron works of Dommeldingen, Germany. The Bian washer was exhibited at the Liège Exposition and the accompanying Fig. 131 shows an elevation and a cross section. The apparatus consists of a horizontal, stationary sheet-metal cylinder *B*, 126 in. in diameter and 118 to 200 in. long and having closed heads, through which the gas enters from *A* and leaves through *C*. The bottom of the cylinder is open and rests its entire length in a water-filled trough, so that

the water fills the cylindrical space almost up to its axis. The horizontal shaft *D*, mounted in the drum casing, carries a number of vertical iron disks covered with a rough wire netting of ⅜-in. mesh. When the shaft is rotated by the electric motor or transmitter *E*, as shown on the sketch, the disks move upward, lifting up that portion of the netting which was dipped in the water. The hot gas entering at a temperature of some 185 deg. C. evaporates the water particles suspended in the network of the first few disks, thereby enriching itself with steam, and at the same time lowering its temperature. This reduction of temperature of the gas will be the greater the farther the gas proceeds toward the middle portion of the apparatus, by its always meeting new water drops and veils suspended between the meshes, so

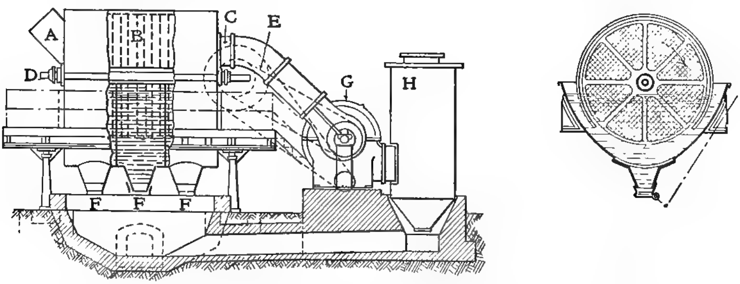


FIG. 131. — Elevation and Cross Section of the Bian Washer.

that finally its temperature is no longer sufficient to evaporate the water. At this point the process is reversed, the cold-water globules of the network effecting a condensation of the steam which was generated in the first part, and which has absorbed the greater portion of the suspended dust particles, so that now the heavy solid constituents are through condensation separated from the lighter gaseous molecules and fall down in the form of drops to the bottom of the trough.

Sluice valves *F*, at the bottom of the drum casing, allow of the removal of the mud at certain intervals. An automatic spraying device, not shown in the drawing, is used to clean the network of the disk from dirt so far as the latter is not washed off from the disks dipping into the water. Cooling water enters the drum continuously in a direction opposite to the gas flow, and partition walls, arranged from the bottom half of the casing, force it to proceed regularly and in stages toward the other

side, so that the coolest water is used for condensing the suspended water vapor, while the hottest part serves for raising steam. From this apparatus, where the main portion of the dust is eliminated, the gas is sucked through a centrifugal hydraulic fan *G*, where it is still further cleaned, to be finally pressed into the dry scrubber *H*, where the excess of moisture is removed.

Besides eliminating the dust, the Bian washer also absorbs the carbon dioxide which is contained in varying quantities in the blast-furnace gas, so that the composition of the gas is also improved. A dust content of 10 or 12 g. per cubic meter can be reduced to 0.5 g. per cu. m., or 0.22 grain per cubic foot, while the temperature of the gas is lowered almost to that of the cooling water (30 deg. C.). Of course, there is a corresponding reduction of volume effected. The consumption of cooling water in a combined plant of this type, when the gases are not hotter than 100 deg. C., amounts to 1 liter per cubic meter, or 7.5 gal. per 1000 cu. ft., and for the fan, 0.5 to 1 liter per cubic meter, or 3.7 to 7.4 gal. per 1000 cu. ft. The total consumption is, therefore, not higher than 2 liters per cubic meter, or 15 gal. per 1000 cu. ft. For gases over 100 deg. C. the amount of water consumed is 2 liters per cubic meter for the washer, and 1 liter per cubic meter for the fan (7.5 and 15 gal. per 1000 cu. ft. respectively). The power required for driving both washer and fan is about 45 h.p. for a blast-furnace plant of 100 tons daily capacity. The speed of rotation of the washer shaft depends upon the temperature of the gas and of the cooling water, and averages 10 to 12 revolutions per minute.

The first cost of the combined cleaning plant, including fan and motor, is $8350 in Germany. The cost of attendance and up-keep, as well as the floor space, is also small, the construction of the apparatus being very simple. The dirt must be drained once in 24 hours from the bottom of the trough.

Unfortunately the Bian washer in the combination described does not clean the gas sufficiently for use in gas engines, so that additional scrubbers or fans have to be added. But for use in blast stoves, under boilers and in furnaces, the degree of purity of the gas is sufficient. There are a few other makes, such as the Salien washer in England, which show the principal features of the Bian and need not here be further discussed.

THE CENTRIFUGAL-FAN WASHER

Coming to the centrifugal-fan washer, its construction is so well known that no detail drawings are required to explain the working process. The water is injected in finely atomized rays at some convenient point of the intake, being there mixed with the hot gases and partly evaporized to steam. Through the action of the fan blades it is rapidly whirled round and finally thrown toward the walls of the spiral casing. Obviously the centrifugal fan was designed for moving gas under low pressures, at low cost, and against low resistances, at the minimum expenditure of power, but with no intention of combining with this action that of the washer. Therefore no high efficiency of cleaning in these hydraulic fans can be expected. As was said before, the separation of the solid dust particles from the gaseous molecules does not take place inside the periphery of the fan blades, but on the water-covered inner surface of the fan casing. The inner space between the blades simply serves for the preliminary admixing of water vapor and dust.

As the eccentric position of the blades in the casing is harmful to the efficiency of the cleaning process proper, which is characterized by the enforced frictional contact between gas and water on the inner fan casing, to secure such a degree of purity of the gas as is necessary for gas engines at least three fans have to be arranged in series. In the first fan the water spray will be transformed to steam through the hot gases, while the two others will condense the steam and so have a similar effect as was explained in the Bian washer. Of course, fresh water has to be injected into each of the three fans and the consumption is high. This fact, together with the important point that hydraulic fans have to be built heavier and use very much more power for handling the same volume of gas than do ordinary dry fans, justifies the conclusion that it is uneconomical to employ this type of apparatus in its present form in a gas-cleaning plant. It may, however, be used in addition to washers specially designed for the purpose, to draw the gas through the water and also as means for drying the gas by separating through centrifugal action the heavy water particles from the lighter gaseous molecules.

THE THEISEN WASHER

A third form of washer, and one that must be regarded as the most efficient of all constructions discussed, is the Theisen

washer. Its principal feature is a forced contact between the gas and spraying water, driven against a cylindrical envelop by fan blades at oblique angles to the axis of rotation, the number of revolutions of the drum being 850 per minute.

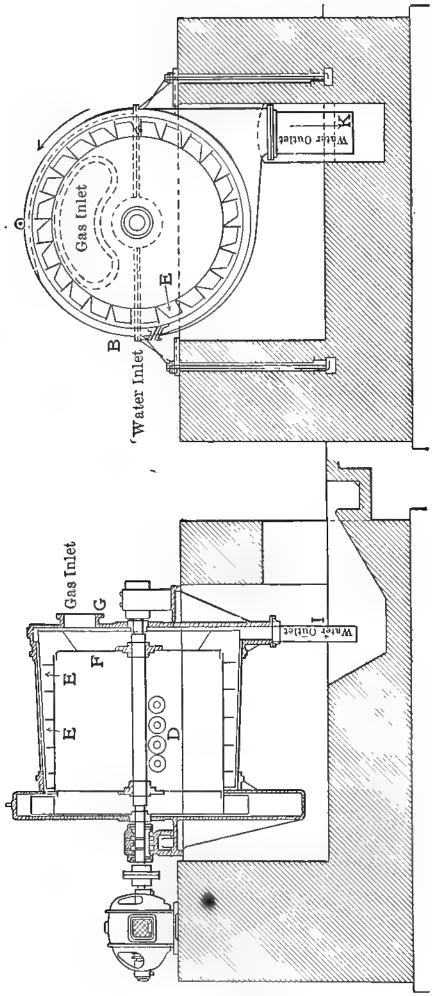


FIG. 132. — Longitudinal and Cross Section of Theisen Washer.

Figures 132 shows a longitudinal and a cross section. Gas enters at *G* and passes out at the lower side of the opposite end at *K*, flowing in an opposite direction to the water, which enters through the openings *B* in the side and discharges through *I*.

The electric motor at the left gives motion to the drum *F*, carrying the small veins *E;* this forces the water to form a film flowing from left to right, through which the gas must pass in an opposite direction. The hot gas vaporizes some of the water on first contact and at the same time gives up the larger and heavier particles of dust. The vapor formed moistens the fine dust remaining in the gas and makes it take up the water more easily at its farther outlet. A wire screen covers the inner wall of the casing, thereby causing the water to bubble and offer a larger surface to the gas. Obviously the efficiency of the process will be the better the greater the frictional difference between the respective gas and water films, the longer the duration of the enforced contact and the greater the temperature difference of the two media; therefore it is claimed that the gas can be led from the dry-dust catcher directly to the washer without previous cooling, its heat being thus utilized for vaporizing the water and for wetting the dust particles through their mixture with steam.

Figure 133 is an elevation of the Theisen washer showing its constructive details. It is seen that the rotating drum carries on its cylindrical surface oblique veins forming a continuous spiral curve. The front part of the drum acts as a suction fan. Gas enters at *a* and is vehemently thrown against the inner wall of the stationary casing, which is covered with wire netting. The veins force it along a spiral path with great rapidity and finally eject it through the blower *c* into the discharge duct *d*. Cooling water enters at *e*, whence it is discharged into the ring *f*. Taking part in the rotating motion of the drum, it is forced to overflow and spread. The hot gases meeting the water spray evaporate it, being cooled at the same time. Washing water is introduced at *g*, entering in tangential direction. Its way of travel is opposite to that of the gases, discharge taking place at *h*. On account of the high speeds employed, water cooling of the bearings is provided at *i*. In the latest constructions the arrangement *e* and ring *f* for supplying extra cooling water have been abandoned. Since the washing water is preheated by the hot gases, it evaporates more quickly than does the cooling water, and an abundant evaporation is desirable for the cleaning effect which it entails. So in this apparatus the same stream of water serves both to cool and clean the dirty gas, which emanates purified and colorless.

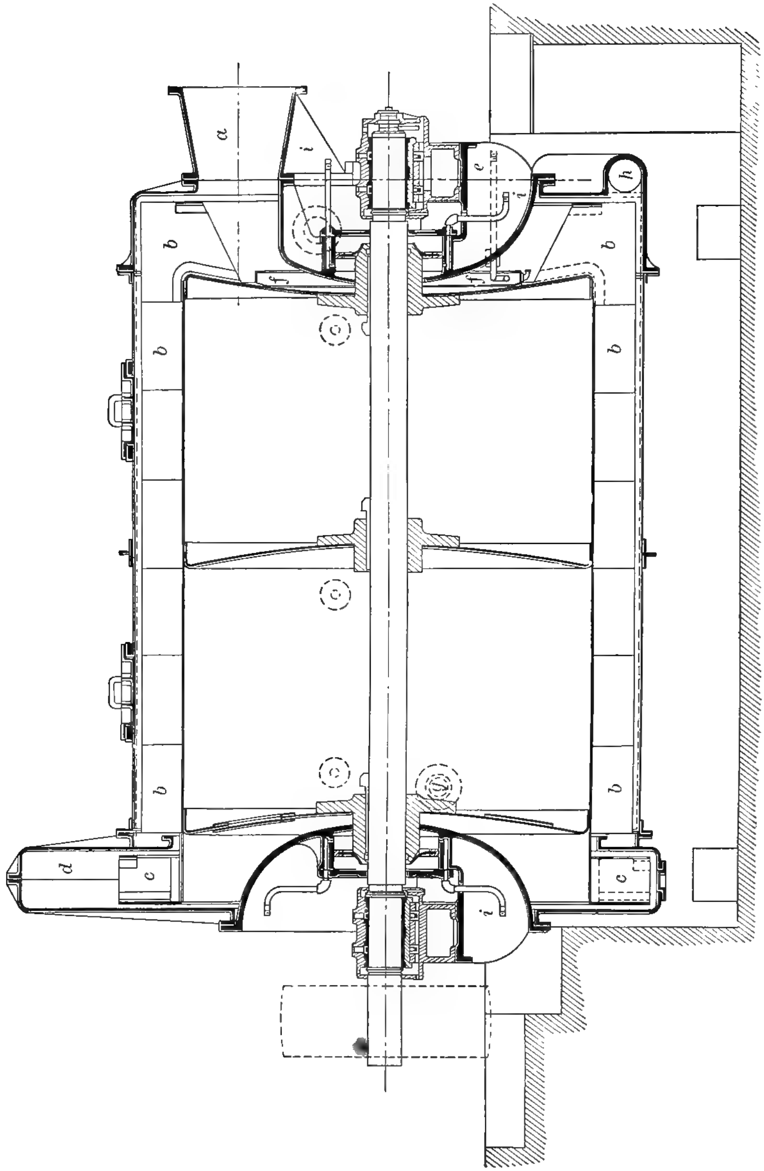


Fig. 133. — Construction Details of Theisen Gas Washer.

The temperature reduction of the gas is remarkably high, ranging from 144 deg. to 30 deg. C., though the heat absorption effected by the cooling water is comparatively small, its tem-

perature being 40 deg. C. before and 39 deg. behind the washer, and a quantity of 1.1 liter being consumed per cubic meter of gas (9 gal. per 1000 cu. ft.). The washing water is fed from elevated tanks, runs through the apparatus and is discharged into clearing ponds. There the dust is allowed to settle and the water is elevated through air-cooled radiators back to the tanks by means of pumps. The actual consumption of fresh water can therefore be reduced to a minimum. The apparatus is, of course, self-cleaning. The accompanying table gives the numeric results which have been obtained with Theisen washers in four German iron-smelting plants in the course of several years' operation. The table is self-explanatory. Fig. 134 shows the reduction of bulk

TABLE 7

SHOWING RESULTS ATTAINED WITH THEISEN WASHERS AT FOUR GERMAN BLAST-FURNACE PLANTS

	HOCHDAHL		SCHALKE	HÖRDE		ROMBACH
	I. Apparatus Hot Uncleaned Gas	II. Apparatus Hot Uncleaned Gas		I. Apparatus Cool and Cleaned Gas	II. Apparatus Cool and Cleaned Gas	
Dust contents of gas before Theisen washer g. cu.m.	6 (2.6)	6 (2.6)	3-4(1.3-1.7)	2.5 (1.1)	2.34 (1.0)	2 (.87)
after Theisen washer (grains per 1000 cu.ft.)	0.04 (.017)	0.02 (.008)	0.004 (.008)		0.01 (.004)	0.02 (.008)
Water contents of gas before Theisen washer g. cu.m.	17.8 (7.8)	24 (10.4)	15% Vol.	32 (13.9)	36.21 (15.8)	42 (18.3)
after Theisen washer (grains per 1000 cu.ft.)	7 (3.1)	5 (2.2)	12-20% "	3.45 (1.5)	3.013 (1.3)	32 (13.9)
Temperature of the gas before Theisen washer deg. C.	144	158	144	46	45	43
after Theisen washer	30	37	30	33	28	36
Volume of gas per hour (cu.ft.) cu.m.	17,200 (607,160)	12,000 (423,600)	10,200 (360,060)	12-15,000 (529,500)	6,000 (211,800)	9,000 (317,700)
Temperature of water before Theisen washer deg. C.	14	7	12	28	20	18
after Theisen washer	39	40	55	37	34	19
Cooling water consumed per hour cu.m.(cu.ft.)	18.9 (667)	12 (424)	10.2 (360)	12-16 (565)	7 (247)	10.2 (360)
per 1 cu.m. gas liter (gal. per 1000 cu.ft.)	1.1 (8.22)	1.0 (7.48)	1.0 (7.48)	1.04-1.06 (7.78)	1.15 (7.93)	1.13 (8.45)

and floor space of cleaning plant effected by the adoption of modern high-speed centrifugal washers against scrubber plants formerly employed. Both forms of apparatus are drawn at the same scale for a capacity of 80 h.p. in gas engines. The total

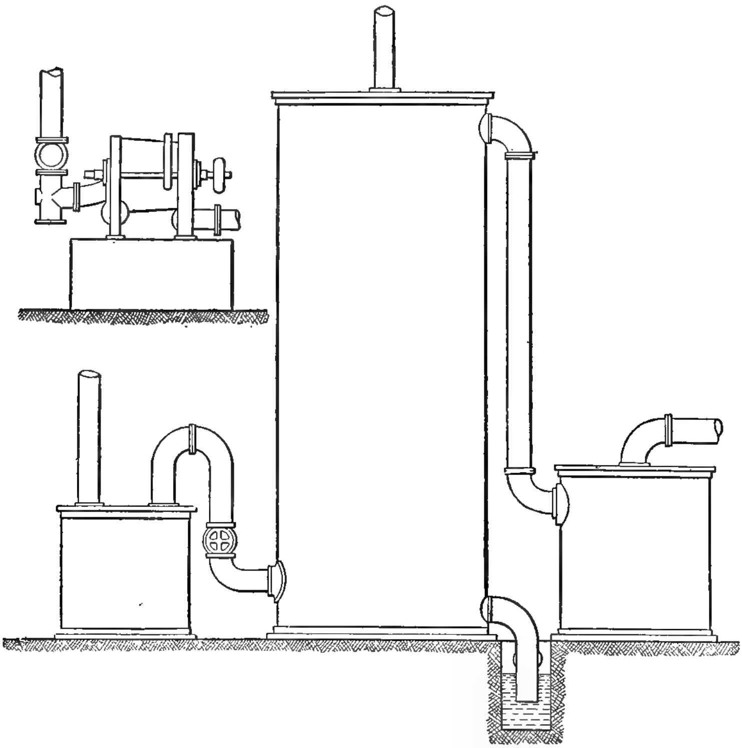


FIG. 134. — Relative Size of Ordinary Wet and Dry Scrubbing Plant and of Theisen Washer for the same Gas Capacity.

cost of operation, including power required and water consumed, of the Theisen washer amounts to about 30 per cent. of the cost of the hydraulic washers discussed before. The purity of the blast-furnace gas thus obtained is equal to that of atmospheric air in the respective iron-smelting plants, and sometimes superior.

FIGURES FROM GERMAN PRACTICE

In conclusion, I give the results recorded by Meyes Zweibrücken in an address delivered in November, 1905, at Saar-

brücken, Germany. I select the data having special reference to the operation of plants working with Bian and Theisen washers, which are the only types deserving consideration in modern practice. Fig. 135 shows a cleaning plant of a capacity of 20,000 cu. m.

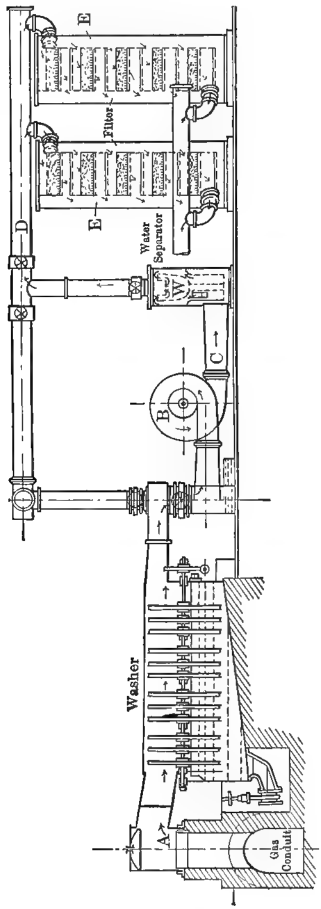


FIG. 135. — Gas Cleaning Plant Equipped with Bian Washer. Capacity 700,000 Cubic Feet per Hour.

per hour (706,000 cu. ft.), of which 18,000 cu. m. are used in hot-blast stoves and under boilers, and 2000 in gas engines. The gas when leaving the blast furnace has a dust content of 8 to 12 g. per cubic meter (3.5 to 5.2 grains per cubic foot). It first passes through two dust catchers and enters at *A* in the Bian washer at a temperature of 740 deg. C., where it is cooled down to from

40 to 30 deg. C., depending upon the temperature of the cooling water. A degree of purity of 2.5 g. per cubic meter (1.1 grains per cubic foot) is reached. The gas is sucked through the washer by means of fan *B* and afterward pressed through a water separator *W*, whence it separates into two streams, the one going through pipes *C* to the blast stoves, the other through *D* to filters *E*, which are filled with slag wool and effect a further drying and cleaning down to 0.02 and 0.01 g. per cubic meter (0.01 to 0.005 grain per cubic foot). The plant costs $12,000 without and $21,000 with dry scrubbers, while for furnace gas the price for a plant of this capacity would only be $41,070 in

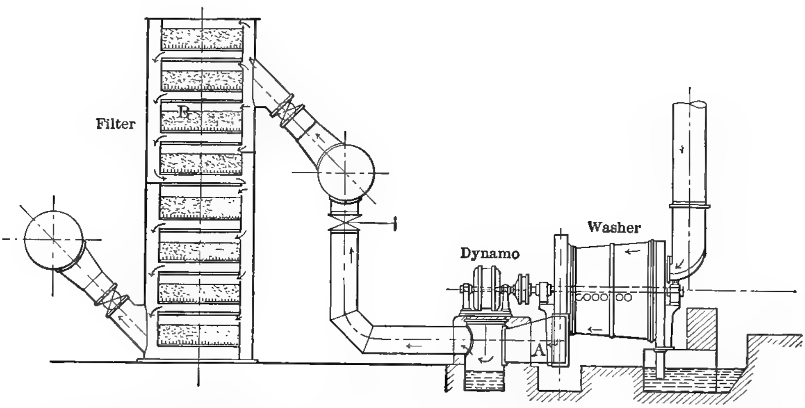


FIG. 136. — Gas Cleaning Plant Equipped with Theisen Washer. Capacity 850,000 Cubic Feet per Hour (Type Universally used in German Iron and Steel Works).

Germany. Thus it is seen that with this type the removal of the last trace of dust contained in the gas adds largely to the expense of cleaning. The above cleaning plant has been in successful operation for the last two years. The water consumption amounts to about 3 liters per 1 cu. m. cleaning gas (22 gal. per 1000 cu. ft.). The power requirement is from 70 to 60 h.p. for power gas or 20 h.p. for stove-heating gas. Basing the figures on 1000 cu. m. as the unit capacity of the gas-cleaning plant, the initial cost of the plant is $1050 and $2080 respectively for the different uses of heat and power. The operating cost is 0.83 to 0.93 cent, or 2.6 cents respectively per 1000 cu. m. Based on 1000 cu. ft. as a unit, the corresponding items are first cost, $30

and $60, and operating expenses 0.023 to 0.026 cent and 0.730 cent respectively.

Figure 136 shows a plant equipped with Theisen washer. The gas coming from the dust catcher contains only from 1 to 1.5 g. of dust per cubic meter (0.43 to 0.69 grain per cubic foot) and has a temperature of 40 deg. C. It goes directly to the washer, leaving at *A* and containing only 0.03 g. of dust (0.013 grain per cubic foot). In the dry filter *B* it is further cooled to 25 deg. C., and when entering the gas engine possesses a degree of purity which is guaranteed, namely, 0.02 g. per cubic meter, or 0.01 grain per cubic foot. There are two Theisen washers, each handling 24,000 cu. m. per hour, or together, 48,000 cu. m. (1,694,400 cubic feet).

One washer delivers gas to four gas engines, of 4800 h.p. combined capacity. It consumes 15 cu. m. (530 cu. ft.) of water per hour, and requires about 100 h.p., that is, 2 per cent. of the engine output, as motive power, which is, indeeed, an excellent performance. The plant was put in active service early in 1903 and has been running without interruption ever since, giving complete satisfaction. The cost of this plant is $33,300, or based on 1000 cu. m. as a unit the first cost is $830 and the operating cost 1.3 cents per hour. For 1000 cu. ft. the corresponding items are, first cost $23 and operating expenses 0.037 cent. The various items for the three different gas-cleaning systems, namely, scrubber plants, slowly revolving apparatus, and high-speed centrifugal washers, having been based on the same unit of 1000 cu. ft. plant capacity, and on the same general conditions of operation, a comparison can now be made which is graphically represented in Fig. 137, showing first cost, power requirements, water consumption, and operating expenses.

The comparison is based on the assumption that 1 h.p. costs ¼ cent, leaving out the value of the blast-furnace gas, and neglecting amortization, but including regular attendance, lubrication, repairs, and up-keep. These tables teach us that all factors which determine the industrial economy of gas-cleaning plants are in favor of the adoption of high-speed centrifugal apparatus. Besides the greatest advantage, namely, the reduction of floor space and bulk, it is seen that also the first cost, the power required, the water consumption, and the other operating expenses of modern cleaning plants are greatly reduced against what

obtains in plants of the type of the Lackawanna, the rate of reduction of the various items being 50, 40, 82, and 50 per cent., respectively. Regarding the relative values of the slowly revolving and high-speed washers, it seems that, while the former have some merit for cleaning the whole mass of gas for furnace

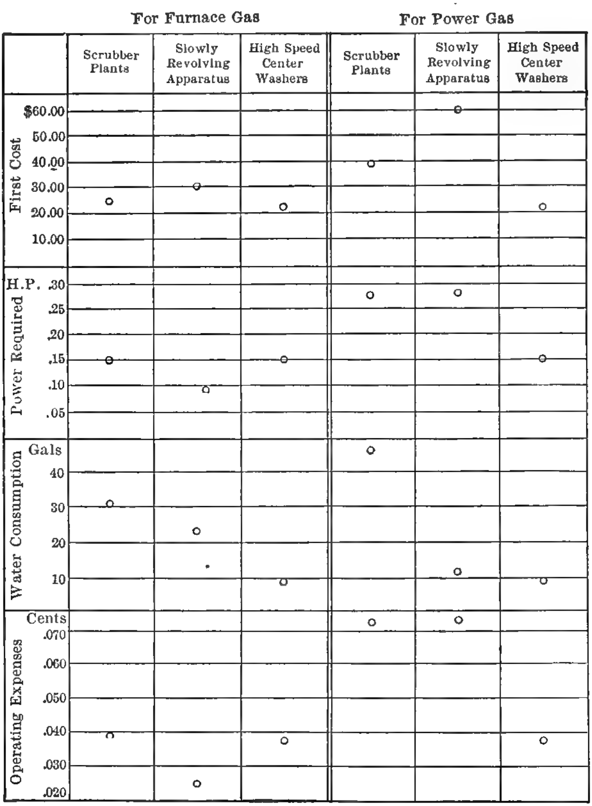


FIG. 137.

heating, the latter must invariably be adopted when the gas is to be used in gas engines. It is better for reasons of simplicity and all-round economy to employ, besides the unavoidable dry-dust catcher, only one system, and the most efficient, in a plant, and to subject the whole mass of gas to a thorough cleaning process, regardless of whether it is to be used for heat or for power purposes. If it should be found sufficient that for the first-named

application the dust contents may be higher, say 0.1 g. per cubic meter, or 0.043 grain per cubic foot, then the initial cost and power requirement of a high-speed centrifugal set will of course be even lower than the values recorded above.

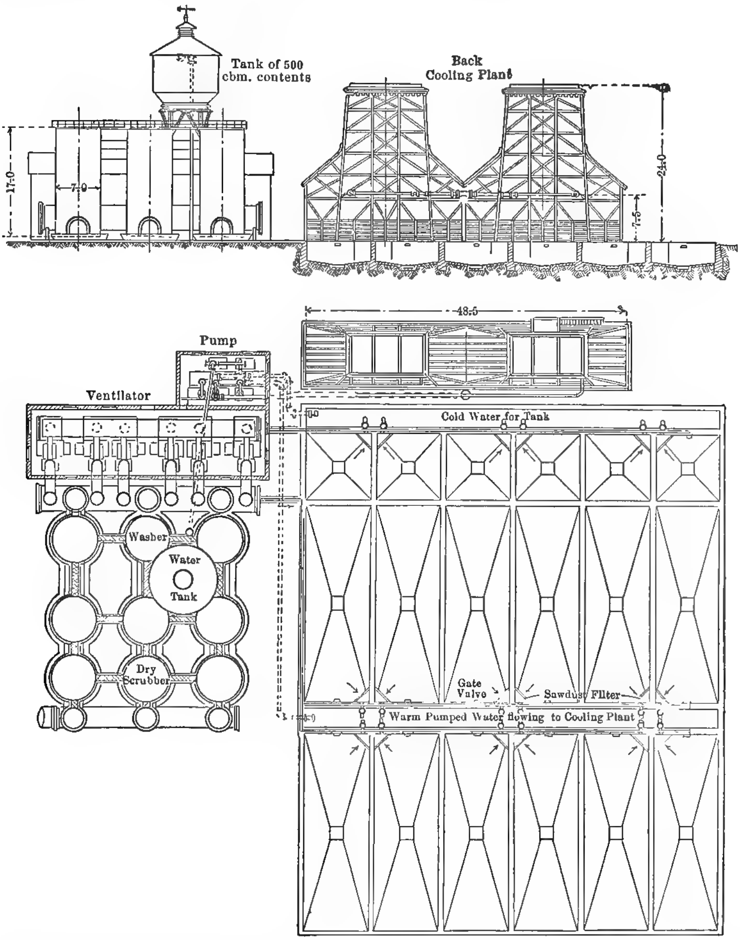


FIG. 138. — Back Cooling Plant for Gas Washing Water (Zschocke System).

To give an idea of the proportions and the layout of a complete gas-cleaning plant, embracing not only centrifugal rotating and stationary washers but also an equipment for clarifying and back-cooling the water, Figs. 138 and 139 are presented. They give

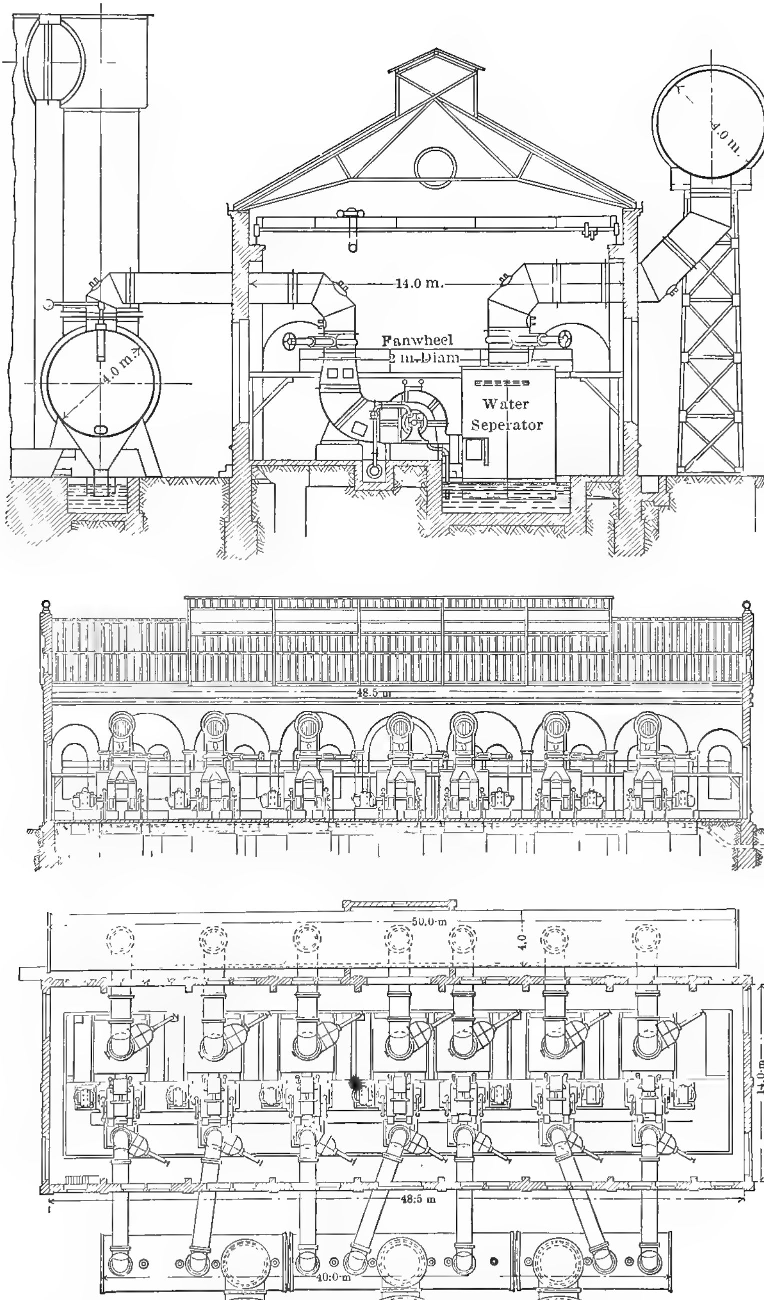


Fig. 139. — Largest Gas Cleaning Plant in the World, Handling 12,708,000 Cubic Feet of Blast Furnace Gas per Hour.

the details of what at present is the largest gas-cleaning plant in the world, built by the Zschocke Machine Works, of Kaiserslautern, Germany. The plant handles 360,000 cu. m. per hour (12,708,000 cu. ft.), which corresponds to a daily output in pig iron of 1800 tons, approximately. Part of this amount, namely 40,000 cu. m. or 1,412,000 cu. ft. per hour, is used for operating gas engines, being subjected to an additional cleaning process. The washing, spraying, and cooling water is cleared, cooled, and used over again. This part of the plant is shown in Fig. 138 which is self-explanatory. The centrifugal fans are all combined in a special house, of which Fig. 139 gives an elevation and plan. There are seven fans, each having a wheel diameter of 2 m. (6.56 ft.), driven by electromotors of 200 h.p. normal capacity, running at 600 r.p.m. The quantity of water injected is 1.5 liters per cubic meter or 11.2 gal. per 1000 cu. ft., which is very low. The power required for each fan is 150 h.p. or 1000 h.p. for the complete plant. Between scrubbers and gas engines a holder of 15,000 cu. m. (529,500 cu. ft.) is inserted.

Figure 140 shows a spraying tower or scrubber built by Louis Schwartz & Co., of Dortmund, Germany, for handling 60,000 cu. m. or 2,118,000 cu. ft. of gas per hour. The tower is 28 m. (93.8 ft.) high, and is parted into three sections of which the uppermost is sprayed from above, the lower ones from the side. The mud which accumulates at the bottom is eliminated by a dredge.

In conclusion I wish to emphasize again that in addition to thorough cleaning from dust it is absolutely essential to free the gas from excessive moisture, either by cooling it or throwing the water particles out by centrifugal action, so far as this is mechanically possible, or by passing the gas through efficient dry sawdust scrubbers and filters. If to the changing temperature, composition, and calorific value of blast-furnace gas, and to its other fluctuating properties, we add a constant quantity of water, as is done in all the apparatus described, the uniformity of the combustion process is certainly more endangered, and the only safeguard against the irregular and inefficient working consists in reducing the amount of moisture to a minimum.

DETERMINATION OF DUST PARTICLES IN POWER GAS (SARGENT)

"Apparatus for cleaning gas depend upon the purpose for which the gas is to be used. Cleaners vary in design and opera-

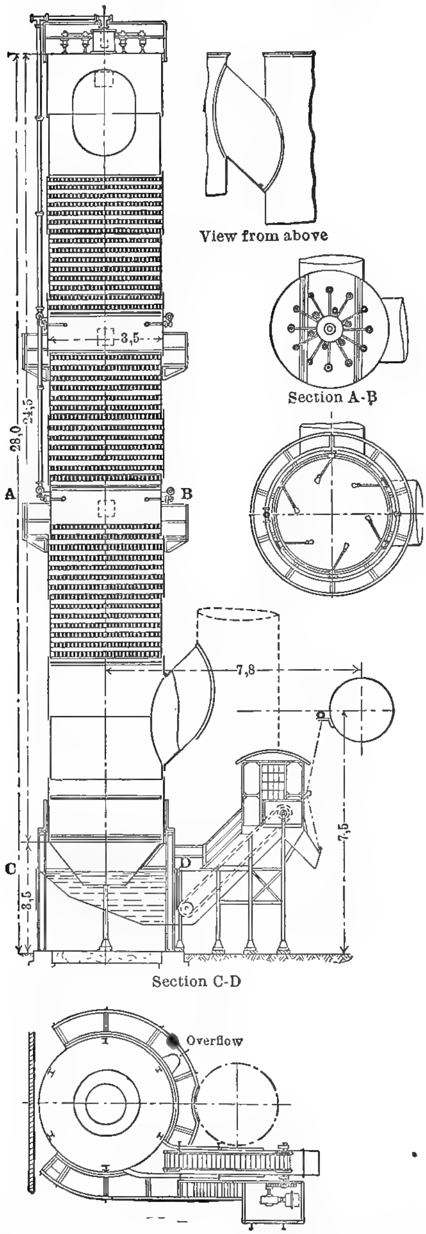


FIG. 140. — Elevation and Cross Sections of Scrubbing Tower for Wet Cleaning, Handling 2,118,000 Cubic Feet of Gas per Hour.

tion, and have to be cleaned when the gas delivered contains more dust than allowable for the purpose for which it is to be used. An apparatus which will separate every atom of dust from the gas passing through it and leave it in such shape that the grains or grams of dust per cubic foot of gas can be determined is an essential accessory for a steel plant using gas cleaners for furnace gas. The ordinary method of determining the quantity of dust in air or gas is to make a filter of a glass tube filled with absorbent cotton, through which the air to be filtered flows. The gas is measured through a test meter, and the cotton is weighed before and after. This method gives accurate results if the cotton always has the same density throughout the tube, and is not hydroscopic. The cotton may be packed in so loosely that some of the dust will work through, and unless the cotton is carefully dried over calcium chloride and weighed several times, a long and tedious process, errors will naturally arise.

NEW TESTING APPARATUS

"Experiments have shown that if two cotton-filled tubes are used in tandem, the second will increase in weight, showing that some of the impalpable dust is not retained by the first tube. A new apparatus for testing the percentage of dust in gas is being used in American steel works. In this the filtering medium is simply a diaphragm of white filter paper, through which the gas percolates, but on account of the minute interstices of the medium, every atom of dust is collected. When two filters are used in tandem, the second does not increase in weight, showing that no dust permeates such a filtering medium. The complete self-contained apparatus consists of a portable case containing an accurate test meter, two filter holders complete, cross connected to $\frac{3}{4}$-in. brass pipes, so that gas to be tested may flow over the mouth of either filter, and hose connections, allowing the gas passing through the filter paper to be accurately measured through the test meter. When the percentage of moisture in the gas is desired, the gas is passed through a cooling coil, where most of the moisture is condensed and precipitated in a collecting bottle. After passing the cooling coil, the gas is passed through three or four bottles of calcium chloride, removing effectually any further moisture in the gas before it is metered or its calorific value is

determined. When the determinations are merely for finding the percentage of dust, the cleaned gas, after leaving the meter, is mingled with the main supply, and burned or wasted to the atmosphere. The cleaned, dried gas may be passed through an automatic calorimeter by which the British thermal units are determined, as well as the hydrogen in the gas. A complete record of the dust and calorific value is an indication of the internal furnace conditions, desirable in the economical manufacture of steel.

CONTINUOUS DETERMINATIONS

"By using two filter holders, continuous determinations can be made. By the proper manipulation of the valves, gas can be passed through either filter while the dust collected in the other per cubic foot of gas burned is being ascertained. On account of the moisture in the gas softening up the filter paper, a wire gauze is inserted under the filtering mediums, which prevents the weight of the dust from tearing it. As the deposited dust and filter paper remain more porous if kept warm and dry, an incandescent lamp or candle is burned under the filter holder in use."

Since the question of gas cleaning cannot, by any means, be regarded as having been definitely settled, I give in the following some additional data from German practice, which were contributed to this subject by K. Reinhardt of Dortmund, at a recent meeting of the Iron and Steel Institute, in London. These data are of special interest in that they diverge in some instances from what was said in the preceding; also they will serve to enlarge upon certain phases of the problem which were not fully discussed by the author.

COOLERS AND FANS

"The coolers or scrubbers are vessels in which the gas flows from the bottom to the top, and the water from the top to the bottom. The water must be finely sprayed in order to moisten the dust, and thereby increase its weight and cause it to settle to the bottom. At the same time the gas is cooled in the scrubbers in which the water vapors are condensed, and the dust is deposited.

"The vessels are either empty, in which case the water is finely divided by spraying nozzles, or the interior is arranged with sieves, wire netting, coke or wooden trays. The best example of the latter form is the Zschocke scrubber.

"The interior of the Zschocke scrubber consists of a series of wooden trays, one above the other, intended to reduce the velocity of the falling water, and by reason of their special form to divide the water into fine streams, so that the large surface exposed may effect a satisfactory cooling of the gas. The precipitated dust is removed at the bottom of the scrubber.

"The fans employed for the purification of the gases as constructed by R. W. Dinnendahl, at Steele, only differ from ordinary air fans in the construction of the vanes and bearings, which are of a much heavier construction, to cope with the injection of water and the higher temperature of the gas. They are provided with a water inlet at the suction opening, and with an arrangement, as in disintegrators for pulverizing the water, so that a sort of water curtain is formed through which the dust has to pass. The cohering particles of dust and water are separated by centrifugal action, through which these particles are thrown against the inner circumference of the fan casing. The under portion of the fan casing opens into a tank, from which the separated slimes flow away and the purified gas escapes at the top outlet. The method of purification resembles that of the Theisen apparatus, except that in the former the passage for the opposing action of the gas and water is not so long.

"The usual sizes of gas-cleaning fans, according to Dinnendahl, are from 15,000 to 70,000 cu. m. of gas per hour, requiring from 40 to 110 h.p. The circumferential velocity of the impellers is up to 56 m. per second, with a diameter of from 1.1 to 1.75 m. For 1 cu. m. of gas from 1½ to 2 liters of water are required, and the dust is reduced from 3 g. to 0.2 g.; as a rule, the percentage of dust is reduced to one-tenth of the percentage before washing.

"When two or more fans are arranged parallel to one another for the purification of large quantities of gas, it is often difficult to obtain outputs equal in quantity and quality. It is therefore advisable to provide regulating dampers behind the fans, and, above all, to make the mains, both before and after the branches to the fans, of large diameter, so that they can at the same time act as air vessels. As a certain preventive of the above difficulties, which are often of a very annoying character, the author can only offer one suggestion — namely, to drive the fans and the electromotors alike with the same speed in such a manner

that their axes could be connected with friction couplings, so that the fans produce equal differences of pressure.

DRYING THE GAS

"Of the other purifying apparatus employed, only the Bian cooler may be mentioned. This consists of a horizontal shaft turning within a cylindrical casing and carrying a number of disks of wire netting. The lower halves of the disks dip into water, and the gas passes through the meshes of the upper halves. The purification of the gas is continued in centrifugal apparatus until the desired degree of cleanliness is attained, after which it has only to be dried. This is effected by forcing the gas through a series of layers of wooden fiber or wool in large cylindrical casings, to which it yields its water. Naturally the resistance caused in passing through the layers of wool requires a large expenditure of power, and the renewal of the wet wool, together with the cost of attendance, necessitates the installation of a spare drier. Large vessels containing various materials through which the stream of gas is forced, with frequent changes of direction, are employed for the separation of the water, and these vessels are further aided by long pipes with frequent changes of direction. If a large gas holder is erected between the cleaning plant and the engines, in addition to its quality as a pressure regulator, it does excellent service in the separation of water, and renders the previous drying of the gas and the expenditure for attendance on the plant and power superfluous.

"It must here be mentioned that in several iron works it was not found possible to reduce the percentage of moisture in the gas arriving at the engine to the point of saturation at the corresponding temperature of gas. In such cases, after the supply of water to the scrubbers had been cut off, so that they were only employed as dry coolers or purifiers, the gas was not so perfectly cleaned, but was drier, and worked with less harmful results in the gas motors than before.

"In no case does the gas contain any suspended water — that is, no water above the quantity at the point of saturation at the corresponding temperature.

"This temperature is in most cases the same as the temperature of the air, or only a few degrees higher. In a few cases the

percentage of water is even lower than that corresponding to the point of saturation at the temperature of the gas, but this is only possible when the water used for cooling is at a very low temperature, and the gas is cooled to below the temperature of the gas arriving at the end of the gas main.

"A further cooling of the gas would be of great utility, favoring the separation of water and purification, and thereby assuring the continual working of the gas engines without disturbance.

"All smelting works have centrifugal apparatus in use for removing the fine dust; and, indeed, about half of them have scrubbers or Bian coolers with fans, and the rest scrubbers with Theisen apparatus, Theisen apparatus alone, or fans alone. The respective merits of the various apparatus or processes cannot well be ascertained from the information received from the iron works, as it is not easy to reduce the results to a common basis. The following results nevertheless are, perhaps, of interest:

COMPARATIVE RESULTS

"The power expended in cleaning 1000 cu. m. of gas per hour varies mostly between 6 and 13 effective horse-power. Accordingly the power expended in cleaning varies from 1.8 to 4 per cent. of the power obtained by the purified gas.

"The amount of water used for cleaning varies greatly. It requires on an average from 3 to 8 liters per cubic meter of gas, and is naturally dependent on the temperature of the water.

"Generally speaking, the water used with centrifugal apparatus alone is less than when it is employed in combination with scrubbers. Similarly the cost of cleaning varies considerably, and includes interest and depreciation of the purifying plant (0.03 to 0.06 pfennig per cubic meter).

"The percentage of dust in the gas after the dry purification is on an average 4 to 6 g. per cubic meter. In a few cases, however, it is only 1 to 1.5 g. In most instances the gas for working the motors is reduced to a percentage of 0.015 to 0.03 g. of dust per cubic meter, in a few works even to 0.005 to 0.004 g. per cubic meter.

"All these remarks concerning the percentage of dust are to be judged from the point of view that the determination of the same at one and the same iron works, if not absolutely correct, will

always be proportionately exact; but that this latter will, perhaps, not always be the case of tests carried out by different iron works. It would, therefore, be of importance to adopt a standard method for the determination of the percentages of dust and water, so that all results could be exactly compared.

"If the purification effected by the Theisen apparatus is compared with that by fans, it will be found that, according to the manufacturers, the Theisen apparatus cleans in the proportion of 140 to 1. Thus, for 1000 cu. m. of gas cleaned per hour there is required 5 effective h.p., and per cubic meter 1.15 liters of water on an average. With a fan the cleaning is, on an average, 10 to 1, the power required being 2.2 h.p., and the water used 1.75 liters.

"In order to obtain a similar result, two or three fans would have to be placed one behind the other, which would require, perhaps, 5 to 6 h.p. per 1000 cu. m. of gas per hour, and a consumption of about 4 liters of water per cubic meter of gas.

"From the information supplied by the iron works it is evident that with a Theisen apparatus the proportion of cleaning is between 90 to 1 and 25 to 1, with about 6.5 effective horse-power per 1000 cu. m. gas, and with a fan the proportion is about 12 to 1 and the average effective horse-power 2.3. From two fans, one placed one behind the other, a proportion of cleaning from 50 to 1 to 200 to 1, and power employed from 6.5 to 10 effective horse-power per 1000 cu. m. per hour, has been attained. Without taking the consumption of water into consideration, one Theisen apparatus is approximately equal to two fans.

"With one exception, all iron works possess apparatus for drying the gas as described above.

GAS HOLDERS

"Attention should be called to the fact that about one-half of the works place gas holders between the purifying plant and the motors. The capacity of the holders in proportion to the gas consumption varies considerably. One iron works places a gas holder of smaller size, arranged as an equalizer of pressure, before each engine.

"The pressure of the gas at the engines is on an average from 2 in. to 4 in., but in many plants it is 8 in. and over. The variations in the gas pressure naturally depend on the number of gas engines at work and of furnaces in blast, and on whether the

blast-furnace tops are provided with a double seal or not. As a rule, it is recommended that the gas pressure be maintained as regularly as possible, and not much above the pressure of the atmosphere (about equal to from $1\frac{1}{4}$ in. to $2\frac{1}{2}$ in. of water). This can, of course, only be done by using a gas holder, which, besides being an excellent separator for water, possesses the advantage of preventing the reduction of speed or even the stopping of the gas engines when the supply of gas is suddenly interrupted for a short period, as may happen when only a small number of blast furnaces are at work. Long gas mains of large section also serve as a reserve, although not so effectively, and for a short period tend to equalize the pressure.

INTERVALS FOR CLEANING AND OTHER ITEMS

"The intervals at which the engine or its several parts have to be cleaned vary greatly. From information received from iron works it may be concluded that with gas well cleaned (0.015 to 0.03 g. of dust per cubic meter), and at the same time well cooled and dried, the inlet gear — that is, the parts before the cylinder of the engines — must be cleaned at intervals of two to three months, and a complete internal cleaning must be undertaken every six or eight months.

"In a few plants using gas which is specially clean the engines require less frequent cleaning. In others the inlet gear, throttle valves, and other similar parts require cleaning at periods of fourteen days. At the same time, when the lubrication is not excessive, and even when the gas is not well cleaned, an internal cleaning of the engine every two or three months is sufficient.

"The parts before the cylinder require for cleaning on an average from six to twenty hours, according to the size and build of the engine and the number of men employed, and the internal cleaning requires from two to eight days.

"The quantity of water used for cooling the cylinders and pistons averages 8.8 to 11 gal. per hour and per effective horse-power, of which 2.2 to 2.6 gal. are for the pistons. The consumption of oil in most plants is reckoned at 1 to 1.25 g. per hour per effective horse-power. The consumption of gas has not yet been sufficiently tested to compare the various systems.

"According to trials made at iron works, the heat employed by the engines varies from 2200 to 3300 calories per hour and per

effective horse-power. Most iron works are at present not yet in a position to determine the consumption of gas in their engines, and content themselves with testing the exhaust gases and thereby determining the completeness of the combustion in the motor."

The Economic Relation of Gas Power to Steam Power

The following presentation is founded on the experience and facts gained in the course of several years of actual practice devoted to the careful study of the gas-power problem in Europe. It is advanced at a time when the more serious and responsible leaders of the iron and steel industry in this country seem at last to have been aroused to the possibilities offered by the employment of more economical methods of production, and is submitted as a proof of the commercial superiority of blast-furnace gas-power plants, whether reciprocating piston engines or steam turbines be used in competition.

Among the various realms of application which lend themselves to the efficient utilization of waste gases in these industries, those of the gas-engine drive for electric generators, both direct-current and alternating-current, and for blowing engines have now been developed to a perfect state of standardization and commercial economy. Whether or not it is better to drive the various forms of rolling mills electrically and from a gas-engine-driven central station, or by scattered gas-engine drives, or whether the steam engine is yet the most economical and reliable prime mover to install for this kind of work, are questions which cannot be regarded by the critical observer as having been finally decided. This was explained in a previous chapter.

In comparing industrial developments we must, again, remember that inequalities in conditions, whether they be geographical, economical, or governmental, must always largely affect the point of view and the judgment on questions that are of common interest in engineering matters, especially when the comparison concerns the divergent practice of countries like the United States and Germany.

ELECTRIC CENTRALIZATION IN GERMANY

In a small country with natural resources which are limited but located closer together and distributed more evenly than they

are in the greater part of America, and which have to supply a concentrated industrial area, industries will naturally locate within the coal-mining and iron-producing districts, and by the employment of high-tension electricity will easily extend the commercial radius of power distribution over the whole area of the country. This most natural method which is prescribed by the geographical conditions prevailing on the continent — to make the coke- and iron-producing fields become power-producing fields as well — is, of course, also the most economical, since electric centralization and electric drive all over the works, including auxiliaries, have been adopted in all the latest and largest European plants. An illustration of the extent to which electric centralization has been carried in Germany may be drawn from the practice obtaining in isolated coal mines, which often possess no prime movers for driving the various pumps, hoists, fans, and other machinery. As was mentioned before, these mines have a transformer substation, equipped with motor generators and fly-wheel sets, serving to equalize the load fluctuations, while high-tension electric current is obtained from a central station, sometimes located in a city many miles from the mines. For instance, 50-cycle current of 10,000 volts is transmitted over a distance of 9 km. from the city of Essen to the Matthias Stinne coal mines, where 2000 h.p. are used for driving the various machines. In another case a coal mine which supplies good coal for coking purposes has a coke-oven plant attached to it, and utilizes the waste gases thereof in a gas-engine-driven central station, while the surplus power is distributed by electric transmission to the substations at neighboring mines.

This possibility, to which detailed reference was made in a previous chapter, of utilizing the energy in waste gases by distributing and selling it for light and other purposes in the neighboring industrial districts forces the German engineer, in the determination of the commercial-economy coefficient for a heat-power plant, to place more value on the factor of heat cost than can be imparted to it under the conditions prevailing in this country. How seriously the difference in the valuation of this factor affects the prime-mover problem in central stations can best be seen by studying the estimated calculation made by Iffland to determine the respective merits of various engine drives for a combined coke, iron, and steel plant, where the coal mines are

located so close to the steel works as to fall within the commercial-distribution circle of the electric central station, and are operated from it. The normal power required by all the engines is 42,000 h.p.; therefore the maximum simultaneous capacity which the plant must be able to carry permanently is 21,000 h.p., which is produced from the waste blast-furnace and coke-oven gases.

COMPARISON OF GAS- AND STEAM-DRIVEN CENTRAL STATIONS

We shall consider only two cases: first, a gas-engine-driven central station; second, a steam-turbine-driven central station. All the auxiliary machines are operated from the central station. On account of the difference in consumption of the reversible and non-reversible machines the total capacity of the central station required is found to be 25,000 kw., it being advisable with complete centralization to provide for an ample reserve.

The power equipment in the first case consists of eight gas engines, each having 6000 h.p. normal capacity, and 4000 effective kw. (cos. $\phi = 0.8$). In the second case, five steam turbines each have 10,000 h.p. normal capacity and are directly connected to alternating-current generators of 6800 effective kilowatt capacity (cos. $\phi = 0.8$). The normal capacity of the gas-engine-driven central station is therefore 32,000 kw. total, and of the steam-turbine-driven station 34,000 kw. Most of the machines used in the plant are in constant operation the year round.

Now, assuming that the waste gases have no commercial value whatever, the actual cost, including initial capital outlay and operating expenses for generating 1 b.h.p, is as follows:

	CENTS.
For gas-engine-driven central station	0.44
For steam-turbine-driven central station	0.42

For purposes of comparison, I give the figure that would be obtained by driving with steam engines all over the works. One brake horse-power-hour would then cost 0.75 cent. In this case the steam turbine would be the most economical prime mover to install. However, the assumption that the blast-furnace and coke-oven gases are given for nothing is erroneous. The gases must first be cleaned, as this increases their heating capacity and makes

them applicable for use in gas engines; but this process requires an expenditure of about 1 cent per 30,000 cu. ft.; moreover, they actually have a value as fuel for steam raising. In the plant under consideration, we shall therefore compare the power value of the waste gases when used in gas engines to what obtains when burned under boilers, and so must appraise the gas at a rate corresponding to the reduction of the coal bill. If power can be distributed abroad, the appraising of the gas depends on the disposal of the surplus power and varies with the locality. Estimating coal at $2.50 per ton, and assuming that 7 kg. of steam are raised from 1 kg. of coal, then the value of the blast-furnace gases which are to be used in gas engines is $150,000. The value of the blast-furnace and coke-oven gases available for raising steam is $325,000. With this valuation, the former total cost per brake horse-power per hour is modified as follows:

	CENTS.
Gas-engine-driven central station	0.54
Steam-turbine-driven central station	0.66

With steam-engine drive the cost would be 0.98 cent. It will be seen that the correct valuation of the fuel upsets the former results entirely in favor of the gas-engine-driven central station. Basing the results on the cost of production per ton of marketable goods, of which this plant sells 300,000 tons per year, we arrive at the following:

Gas-engine-driven central station, $2 without and $2.48 with appraising the gas.
Steam-turbine-driven central station, $1.93 and $3.02, respectively.
With steam-engine drive the cost would be $3.35 and $4.42, respectively.

It is seen that the gain effected by the selection of gas engines instead of steam turbines for the central station amounts in this particular case to 50 cents per ton of annual capacity. The figures are of special significance, as they show how much the whole prime-mover question hinges on the valuation of the factor of heat cost. The conditions change, of course, if a plant possesses only capacity for iron and steel smelting and has rolling mills but no coal mines attached to it; and they are again different for a steel plant with rolling mills, but without coal mines, blast furnaces, and coke ovens. It is only in the

last-named case that the pure gas-engine drive — gas-engine central station and scattered gas-engine auxiliaries — is the most economical method.

DATA AND FACTS FROM ACTUAL PRACTICE

However, since theoretical assumptions like those in the foregoing calculations are always regarded by skeptics as uncertain, we may as well base our considerations on such data and facts as were obtained on the Continent in the course of several years of actual practice. We shall, in the following comparison between the respective merits of gas or steam drive for various forms and localities of application, omit the consideration of some items which, on account of their dependence upon local conditions, are apt to make the numerical results rather problematical. By this, I mean especially the items of first cost, interest, amortization, etc., which, according to the latest data obtained in Germany, are found to bear a ratio of blast-furnace gas-engine plant to steam boiler and engine plant of 1 to 1.3, while in this country the items of first cost can hardly be regarded as being even on a parity. Some power-plant engineers hold that the excess cost of a gas plant over a steam plant runs from 7.4 to 14 per cent., so that, if the annual saving in operation were capitalized at 5 per cent., it would take less than two years to cover the surplus capital invested. Others assume that the capital outlay for a first-class steam and for an internal-combustion plant are equal.

Another feature of uncertainty is introduced into the estimate by the varying practice of rating gas engines, a matter which indeed needs urgent standardization. If there were any disappointments experienced with earlier continental gas-power plants, they were, aside from negligence in gas-cleaning apparatus and methods, almost entirely due to an overrating of the normal capacity of the gas engine, which, owing to the impossibility of carrying an overload over what is determined by its cylinder suction capacity, cannot be expected to compete with a steam engine of the same nominal output.

The cost of water which is consumed in the boilers of steam-power plants and for washing and cleaning purposes in gas-power plants is another uncertain item, widely varying with local conditions. If it is omitted in the following comparison, this operates

in favor of the steam plant, which consumes by far more water. The cost for purifying and back-cooling, too, is much higher than in a gas plant. We shall also confine ourselves to figuring the comparative cost of operation of the central station proper, without including in our calculation auxiliary machines. The calculation will therefore include: 1. Expenditures for maintenance. 2. Attendance and up-keep. 3. Fuel expenses.

As was mentioned before, the method of appraising the blast-furnace gas consists generally in determining the amount of coal which is saved by burning the waste gases in gas engines instead of under steam boilers. But this rather superficial method of valuation gives the gas price regardless of the cost of cleaning and is somewhat incorrect. A better practice developed on the Continent is based on the reasoning that the gas in the gas-engine cylinder is utilized just as directly as the steam is in the cylinder of a steam engine. We shall, therefore, appraise the gas according to its heating value, but compare with the amount of steam generated and not with the corresponding quantity of coal used. It may be said, however, that no standard method of valuation can be accepted, but that each individual case must be treated separately and in accordance with the local conditions.

RESULTS IN THE MINETTE DISTRICT OF GERMANY

The following data, recorded by Ehrhardt, were obtained in the Minette district of Germany, where 1 metric ton of coal (0.9842 ton English), having a heating value of 6500 calories (11,700 B.t.u. per pound), can be bought at from \$2.62 to \$3.57, according to the location. Taking an average steam pressure of 8 atmospheres (113.84 lb. per square inch), which has a total heat value of 660 calories (2619 B.t.u.) and feed water entering at 20 deg. C., there are necessary for generating 1 kg. (2.2 lb.) of such steam 640 calories (2539 British thermal units).

A medium boiler plant with 66 per cent. efficiency will generate under these conditions from 1000 kg. of coal:

$$0.66 \frac{1000 \times 6500}{640} = 6700 \text{ kg. of steam.}$$

1000 kg. of steam, therefore, cost $\frac{\$2.62 \text{ to } \$3.57}{6.7}$ = from 39 to 53 cents, depending upon the price of the boiler coal.

In addition there are wages for firemen and general up-keep of boilers, running the cost per 1000 kg. of steam up to from 56 to 71 cents. Similarly we find:

1000 cu. m. of gas $= 1000 \times 900$ cal. $= 0.66 \dfrac{1000 \times 900}{640}$ kg. steam $= 928$ kg. steam, at a value of $\dfrac{928}{1000} \times (0.39 \text{ to } 0.53) = 52$ to 66 cents.

Or, in English units, 1000 cu. ft. of gas cost 1.47 to 1.89 cents, and 1,000 lbs. of steam cost 25.5 to 32.3 cents, the price varying, of course, with the cost of coal and the location of the plant.

To determine the factor of gas consumption and total gas cost, it can be taken that large gas engines have an average mechanical efficiency of 82 per cent., which is the mean of the two extreme results, 84 and 80 per cent. having been obtained in reliable tests with the earlier types of engines, although in the latest types 92 per cent. has been recorded. Hence, 1 effective horse-power = 1.22 indicated horse-power. At full load an engine of this kind will consume 2.8 cu. m. (98.8 cu. ft.) of blast-furnace gas, having a calorific value of 900 calories (100 B.t.u. per cubic foot). Considering that the work required for running the engine at no load is approximately invariable, but that with decreasing load the gas consumption per indicated horse-power is somewhat increased, the following tabulation for the fuel consumption is obtained:

At 100 per cent. load, 2.8 cu. m. (98.8 cu. ft.) gas per 1 effective h.p. hour.
At 90 per cent. load, 3.0 cu. m. (105.9 cu. ft.) gas per 1 effective h.p. hour.
At 80 per cent. load, 3.2 cu. m. (112.9 cu. ft.) gas per 1 effective h.p. hour.
At 66 per cent. load, 3.45 cu. m. (121.8 cu. ft.) gas per 1 effective h.p. hour.
At 50 per cent. load, 3.7 cu. m. (130.6 cu. ft.) gas per 1 effective h.p. hour.

These figures do not give the best results which can be obtained with large modern gas engines, or under specially prepared test conditions, but they may be relied upon as representing what has been obtained during several years' continuous practice. The losses due to radiation and condensation in the pipe lines have been accounted for by assuming the total steam consumption of engines running all day and night to exceed the net consumption by from 10 to 12 per cent., and with engines running only in the day time by from 15 to 16 per cent. The gas pipes do not, of course, show up any loss of the kind.

COMPARISON OF STEAM AND GAS BLOWING ENGINES

From the region of cheap fuel (1000 cu. ft. of gas cost 1.47 cents and 1000 lb. of steam cost 25.5 cents), I select two blast-furnace blowing engines, working 360 days of 24 hours, or 8600 hours a year.

1. Horizontal gas blowing engine of 600 effective horse-power maximum capacity at 80 r.p.m. The actual mean output throughout the year averages not more than 90 per cent. of the maximum capacity, or 540 effective horse-power. Fuel consumption per hour $540 \times 105.9 = 57{,}186$ cu. ft., having a value of $57.186 \times 1.47 = \$0.84$.

Hence annual fuel cost for 8600 hours =	$7,200
Attendance, maintenance, and repairs, actual cost	3,100
Total operating cost	$10,300

2. Vertical blowing compound engine, working at 5 atmospheres (73.5 lb. per square inch)[1] gage pressure with condensation, and developing 450 effective horse-power at 45 r.p.m., and at full load. To facilitate a comparison it is assumed that blowing engine No. 2 is so constructed as to develop at 60 r.p.m. a maximum capacity of $\frac{60}{45} \times 450$ or 600 effective horse-power. The cost of attendance, which at 45 r.p.m. amounts to $1130, would remain the same, but the expenditures for lubrication and up-keep, which are actually $754.08, would be increased in a ratio of 60 to 45, that is, to $1000, which gives a total of $2130. On account of the low steam pressure and the small stroke volume, the engine works with a later cut-off than that developing the highest economy. Hence, the net steam consumption is found to be 9.5 kg. (20.9 lb.) per effective horse-power-hour. In addition there is 1 kg. (2.2 lb.) per hour for pipe loss, which gives a total of 23 lb. Now, taking as the average annual output 540 effective horse-power as above, we have

Steam consumption per hour, $540 \times 23 = 1242$ lb., having a value of $1.242 \times 25.5 =$	$3.17
8600 hours a year =	$27,200
Attendance and up-keep	2,100
Total operating cost	$29,300

[1] The pressure used in this plant is very low, but no other engine was available for comparison.

or in round numbers, \$30,000, which is almost three times larger than the corresponding item for a gas engine. In other words, the annual saving effected by the use of a gas engine instead of a boiler and steam engine for driving one blowing engine of 540 h.p. actually amounts to \$19,000 a year.

To show that the result is not incidentally arrived at nor is an exception, I give another comparison derived from the district characterized by expensive fuel (1000 lb. of steam cost 32.03 cents and 1000 cu. ft. of gas cost 1.89 cents).

3. Horizontal gas blowing engine for blast-furnace work, single-acting old type, having a gas consumption of 3 cu. m. (105.9 cu. ft.) per effective horse-power-hour, and delivering 600 h.p. nominal at from 60 to 80 r.p.m. The average annual output at from 71 to 72 r.p.m. is 450 effective horsepower. In 416 working days three of the above engines have consumed for attendance, lubrication, and maintenance, including repairs, together \$4854; for 360 working days of 24 hours, or 8600 working hours annually, one engine requires \$4190.

Gas consumption per hour, 450 × 105.9 = 47,655 cu. ft., having a value of 47.655 × 1.89 =	\$0.90
8600 hours a year =	\$7,700
Attendance and up-keep	4,190
Total cost of operation annually	\$11,890

4. Vertical blowing compound condensing steam engine with wide expansion but low-gage pressure (5 atmospheres = 73.5 lb. per square inch). The blowing engine has 450 effective horsepower nominal capacity, and the actual output at 45 r.p.m., and air delivered at from 0.35 to 0.37 atmosphere pressure, is also 450 h.p. Owing to the slow speed and the low steam pressure the net steam consumption is found to be 9 kg. (19.8 lb.) net, or, including losses in steam pipes, 10 kg. (22 lb.) total per effective horse-power-hour.

Steam consumption per hour, 450 × 22 = 9900 lb., having a value of 32.3 × 9.9 =	\$3.20
8600 hours per year	\$27,520
Attendance and up-keep	2,480
Total operating cost per year	\$30,000

Even the employment of an old-type single-acting gas engine effects a saving over the steam engine of $18,000. It is remarkable that the results of the comparison between Nos. 1 and 2 and Nos. 3 and 4, respectively, come out so close, though the types of engines, the local conditions, and the cost of fuel are quite different.

COMPARISON OF GAS AND STEAM DRIVE IN ELECTRIC CENTRAL STATIONS

Taking the actual working time for the prime movers as 300 days of 24 hours, or 7200 working hours per annum, there are, in the region of cheap fuel (1000 lb. of steam cost 25.5 cents and 1000 cu. ft. of gas cost 1.47 cents), available for comparison:

5. Four-cycle gas engine with two single-acting twin cylinders directly coupled to a dynamo of 350 effective horse-power. The engine works at 90 per cent. of its maximum capacity, that is, with an output of 315 horse-power.

Gas consumption per hour, 315 × 105.9 = 33,350 cu. ft., having a value of 33.35 × 1.47 =	$0.49
7200 hours annually	$3,520
Attendance and up-keep	1,540
Total operating cost per year	$5,060

Or based on 1 effective horse-power-hour:

	CENTS.
Operating cost for 1 effective horse-power-hour	0.223
Cost of gas for 1 effective horse-power-hour	0.155
Attendance and up-keep for 1 effective horse-power-hour	0.068
Gas cost per hour	48.8
Cost of attendance and up-keep per hour	21.4

6. Steam turbine, 150 lb. square inch gage, working with condensation and having an average output of 400 effective horse-power all the year round. The steam consumption is 7.2 kg. (15.84 lb.) net, and with 10 per cent. pipe loss 8 kg. (17.6 lb.) total per effective horse-power-hour. The cost of operation comes out as follows:

Steam consumption per hour, 400 × 17.6 = 7040 lb., having a value of 25.5 × 7.04 =	$1.79
7200 hours a year	$12,800
Attendance and up-keep, including condenser	1,200
Total operating cost per annum	$14,000

Total operating cost per 1 effective horse-power-hour	0.487 cent.
Cost of steam per 1 effective horse-power-hour	0.447 cent.
Attendance and up-keep per 1 effective horse-power-hour	0.042 cent.
Operating cost per hour for steam	$1.78
Attendance and up-keep per hour	16.8 cents.

Comparing Nos. 5 and 6, under the assumption that the cost of operation increases in direct proportion to the ratio of capacities, namely, 315 to 400, the total operating expenses per annum of a gas dynamo of 400 h.p. would be $6400, and the annual surplus cost of the turbo-dynamo of the same output would then be $7600.

ROLLING-MILL ENGINES

In conclusion, I give the results obtained with a large blast-furnace gas engine of modern type, built by the Nürnberg Company in Germany. The engine, which on the average works with its nominal load, 1850 effective horse-power, serves to drive a rolling mill and is at work 300 days of 11 hours, that is, 3300 working hours per year. The cost of operation comes out as follows:

Gas consumption per hour, $98.8 \times 1{,}852 = 182{,}780$ cu. ft., having a value of $1.47 \times 182.78 =$	$2.68
3300 hours per year	$8,840
Attendance and up-keep	2,660
Total operating cost per year	$11,500
Total operating cost per 1 effective horse-power-hour	0.188 cent.
Gas cost per 1 effective horse-power-hour	0.144 cent.
Attendance and up-keep	0.043 cent.

In studying these results, it becomes at once apparent how much more economical the employment of double-acting tandem engines of modern construction is over what can be obtained with the old-type single-acting machines, though even with them an enormous saving over the steam equipment has actually been effected. In the accompanying diagrams I give a tabulation of the average cost of gas and steam per 1 effective horse-power-hour for power generation, compared on the basis of varying coal prices in different localities, the coal having a thermal value of 11,700 B.t.u. per pound, and blast-furnace gas having a calorific value of 100 B.t.u. per cubic foot.

1 ton of coal costs	$2.66	$3.14	$3.63
1000 lb. steam cost	0.255	0.289	0.323
1000 cu. ft. gas cost	0.0147	0.0166	0.0189

The fact must not be overlooked that the above calculations are based on foreign conditions and cannot be used for direct comparison with the corresponding items which for the same plant capacity would obtain in this country. This, however, would not affect their relative value to a very large extent.

In the accompanying diagrams the plotted lines in Fig. 141

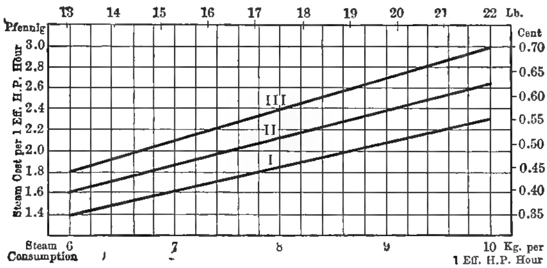


FIG. 141. — Diagram Showing Cost of Steam per Horse-power-hour for Various Coal Prices and Loads.

show the cost of steam and in Fig. 142 the cost of blast-furnace gas per 1 effective horse-power-hour in various localities and for

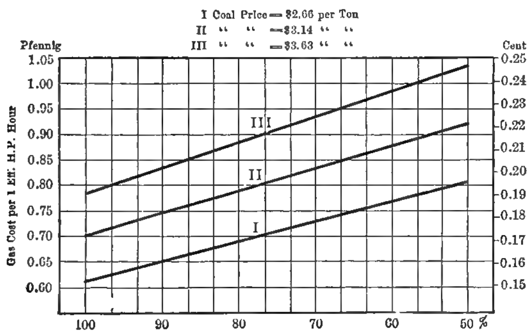


FIG. 142. — Diagram Showing Cost of Blast-Furnace Gas per Horse-power-hour for Various Coal Prices and Loads.

various coal prices and loads. Fig. 143 gives the gas consumption of the early type of blast-furnace engines per 1 effective horse-power-hour at various loads.

In view of these facts, is there any justification for the re-

luctant attitude which some over-conservative ironmasters still feel called upon to maintain? Let us briefly summarize and ex-

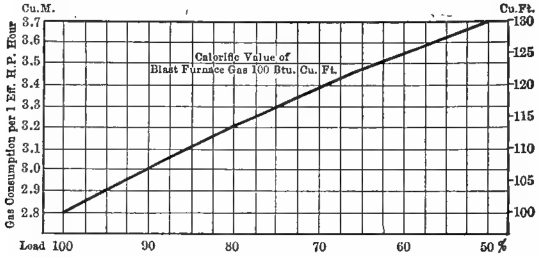


FIG. 143. — Diagram Showing Gas Consumption of Old-type Blast-furnace Gas Engine at Various Loads.

amine the well-worn objections which people not familiar with foreign achievements still believe to be deserving of serious discussion.

OBJECTIONS SUMMARIZED

Backward State of Gas-engine Industry. — There are some types of large gas engines built by up-to-date manufacturers in this country which in practical excellence, reliability, and steadiness of running come up even now to the most exacting requirements and can be relied upon as giving cheap and continuous service under all the varying conditions of heavy service. Moreover, it is only a matter of logical reasoning to expect that the same process of evolution, which has gradually forced upon every progressive steam-engine builder in Germany the necessity to take up the subject of gas-engine manufacture so as to be able to comply with the modern requirements for economy, will similarly affect the large American concerns, and, with that spontaneousness of growth and progress so remarkable in this country, will lead to a national effort to create the best also in this line of machine building.

Higher Initial Capital Outlay. — The present excess cost of a gas plant over a steam plant is too insignificant to warrant any hesitation, the price per horse-power in gas engines being from \$35 to \$40. The larger the plant, the more the two items are even now brought to a parity. Let the power-consuming people disclose their interest in the gas problem and the rising demand for the increased manufacture of and the competition in this type of engines will at once lower their price below that of their competitor, as has been evidenced in Europe.

Cost of Attendance and Up-keep. — With the modern large gas engine of the Nürnberg type, which has become the standard construction for large four-cycle work, and for which accurate data are given in the last paragraph, the actual cost for attendance and up-keep per 1 effective horse-power per hour of an 1800-h.p. engine is equal to the corresponding item of a 400-h.p. steam turbine. This, in the first place, is due to the elimination of that inefficient, wasteful-, space-, labor-, water-, and fuel- consuming boiler equipment. The blast furnace, as the potential source of energy, combines in itself in a most simple and efficient manner both the processes of reducing the ore and generating the power necessary for carrying out the entire series of converting and finishing processes which transform the original ore into marketable steel products.

Floor Space and Other Items of Comparison. — As has been said, the boiler house is eliminated completely, and there is substituted for it the gas-cleaning plant, consisting of a few electrically driven high-speed centrifugal fans, which occupy very little room, consume almost no water, and absorb only from 1 to 2 per cent. of the power developed in the engines. They are self-cleaning, requiring hardly any attention. This factor of efficiency of modern gas-cleaning methods is another point often overlooked by those who have not followed the course of development on the continent. Another no less important point is the much lower consumption of water in a gas-power as compared with a steam plant, which in some localities may become a decisive factor in favor of the first named.

CONCLUSION. — *If, therefore, the surplus power that becomes available by the adoption of economical prime movers can be used in the works, where its value is equal to the corresponding reduction of the coal bill, or if it can be sold to advantage abroad, where its value varies with the local conditions, we shall invariably select the gas engine as a prime mover for central stations. Where beside waste gases no additional coal is used under boilers, or where there is no demand or market for available surplus power, there the steam turbine will always keep its field of usefulness.*

As a further outcome of these investigations the fundamental fact — obvious, though often lost sight of by technical prophets — is re-established, that when predicting the course of future

relations of power-producing methods no sweeping statement must be attempted or accepted. The selection of prime movers must be decided with due consideration of the local conditions by determining, for the different types of engines and modes of action, through careful mathematical analysis, the complete commercial-economy coefficient separately for each individual case.

Available Power and Cost of Operation of a Power Station for Waste Gases from a Blast-furnace Plant

In the preceding chapters I have referred exclusively to the results of investigations such as were made in German and Belgian iron works. They are, therefore, not directly applicable to conditions prevailing in this country. In order to make this important subject more valuable to American engineers I substantiate in the following the views of European authorities by those of H. Freyn, who has made a special study of the introduction and application of gas power in American steel-smelting plants.

The estimative calculation on "The Economy of Gas Engine Installations in Blast-furnace Plants" which Mr. Freyn presented some time ago to the Western Society of Engineers is, indeed, too valuable and comprehensive a contribution to technical literature to be allowed to pass into oblivion.

This is an abstract of the paper:

"The following calculation has been made assuming a new blast-furnace plant of two 400-ton blast furnaces, situated in the immediate vicinity of a large city and having the ordinary facilities for water supply and for handling the raw and finished material. Assuming both furnaces in good operation and assuming a coke consumption of 1900 lb. per ton of pig iron, there will be required $800 \times 1900 = 1,520,000$ lb. of coke per day. This quantity of coke produces approximately 110,000,000 cu. ft. of gas in 24 hours, or per ton of pig iron $110,000,000 \div 800 = 137,000$ cu. ft. of gas. The losses on the top of the furnaces may amount to approximately 5 per cent., so that 130,000 cu. ft. of gas per ton of pig iron produced in 24 hours could be obtained. The average heat value of this blast furnace will be about 90 B.t.u. per cubic foot. The total quantity of gas available for the various purposes in this blast-furnace plant amounts to $130,000 \times 800$

= 104,000,000 cu. ft. of gas per 24 hours or 4,350,000 cu. ft. per hour, having a total heat value of 391,500,000 B.t.u. Modern double-acting gas engines of large capacity, built with the latest improvements and using high compression of mixture, consume less than 9000 B.t.u. per hour per brake horse-power at full-load capacity. The total quantity of gas produced by two blast furnaces of 400 tons capacity each, when used in gas engines for generating power, would operate at least 391,500,000 ÷ 9,000 = 43,500 h.p. If, therefore, all the gas generated by a blast-furnace plant could be used for producing power, there would be available over 50 h.p. per ton of pig iron produced per 24 hours.

"This quantity of 4,350,000 cu. ft. of gas per hour will be divided for the various purposes of the blast-furnace plant as follows: One part of the gas is used for heating the hot-blast stoves, another for operating gas blowing engines, and there is gas required for the auxiliary machinery, such as pumps, hoists, coke and ore-handling machinery, power transmission, compressed air, pig-iron casting machinery, and for lighting the entire blast-furnace plant; some of the gas is also necessary for operating gas engines, serving the gas-cleaning plants, and a certain percentage may be counted for losses in the piping in the engines, the gas-cleaning plant, etc. It will be seen that the total quantity of gas necessary for the operation of the blast-furnace plant itself amounts to approximately 50 per cent. of the total quantity generated, leaving a little less than 50 per cent. available for useful work outside of the blast-furnace plant itself.

GAS REQUIRED FOR HOT-BLAST STOVES

"It is generally figured that about 30 per cent. of the total quantity of gas generated by the blast furnace is required for heating the blast, although this quantity varies considerably according to the quality of the gas, the design and construction of the hot-blast stoves and according to the conditions of operation of the blast-furnace plant in general. For European blast-furnace plants, the figure of 45 per cent. is found frequently in reports endeavoring to determine the available power from blast plants, while in this country the gas necessary for the stoves is estimated in certain instances to be as low as 20 per cent. of the total quantity produced.

"Edward A. Uehling, in his paper entitled 'The Blast Furnace as a Power Plant,' determined by a very careful calculation that the quantity of gas necessary for heating the blast amounts to about 18 per cent. of the total quantity of gas. Other authors assume this quantity to be about 25 per cent. of the total gas for an average blast-furnace plant in the United States.

POWER FROM BLAST-FURNACE GAS

"Assuming 30 per cent., we are certainly on the safe side, and so much more so since in a new blast-furnace plant all the gas leaving the top of the blast furnace would be subjected to a cleaning process, thus removing part of the dust carried along by the gas. The question of cleaning the blast-furnace gas which is required for the hot-blast stoves and the boilers in a blast-furnace plant has not as yet received as much attention in this country as it has in Europe, where most of the large blast-furnace plants have been equipped, during the last two or three years, with extensive gas-washing plants, cleaning practically every particle of gas produced by the furnaces. Very exhaustive tests as to the advantage of cleaning the gas for stoves and boilers have been made by Mr. Emil Hiertz, superintendent of the blast furnaces of the John Cockerill Company, of Seraing, Belgium.

"As far as the consumption of the hot-blast stoves is concerned, he found that by using clean gas the temperature of the stoves could be increased at least 200 deg. F., and it will be seen at a glance that this fact tends to decrease the quantity of gas necessary for obtaining a certain temperature in the hot-blast stoves, so that in the future the percentage of gas to go into the stoves will be materially decreased.

"Assuming the figure of 30 per cent., the total quantity of gas necessary for heating the blast will be $4{,}350{,}000 \times 0.30 = 1{,}305{,}000$ cu. ft. per hour.

GAS BLOWING ENGINES

"A new blast-furnace plant will in the future be equipped with just one steam blowing engine for starting the blast furnaces (unless gas producers should be installed), while the rest of the blowing engines will be operated by gas engines. The quantity of blast required will be 90 cu. ft. per minute per ton of

pig iron produced, or for 800 tons, $800 \times 90 = 72{,}000$ cu. ft. of blast air per minute.

"Assuming that all the necessary blast be furnished by gas blowing engines, the latter will normally have to compress the air to about 15 to 18 lb. per square inch; but as it will be occasionally necessary to blow against a pressure of 30 lb. per square inch, the gas blowing engines must be large enough to do this work. Figuring on a maximum pressure of about 30 lb. per square inch, the work necessary to compress 100 cu. ft. of air against this pressure for adiabatic compression will amount to 8.65 h.p. theoretically, or nearly 10 b.h.p. in the gas engine. As 72,000 cu. ft. per minute have to be compressed, 7200 b.h.p. in gas engines must be provided. The engines would, under these conditions, operate under full load. The heat consumption, as stated before, will be less than 9000 B.t.u. per hour per brake horse-power. (Actual tests on a double-acting tandem Cockerill gas engine show a heat consumption of 8880 B.t.u. per hour per brake horse-power); but assuming 9000 B.t.u. per hour per brake horse-power, 1 brake horse-power-hour will require $9000 \div 90 = 100$ cu. ft. of gas, and 7200 b.h.p. in blowing engines will therefore require 720,000 cu. ft. of gas per hour.

"As previously mentioned, under ordinary conditions the gas blowing engines will have to blow against only 15 to 18 lb. pressure. Taking the lower figure of 15 lb. per square inch, there will be required 5.125 h.p. per 100 cu. ft. of blast theoretically, or approximately 6 b.h.p. per 100 cu. ft. in the blowing engines. For the total blast of 72,000 cu. ft. per minute there will be required 4320 b.h.p. The gas blowing engines are supposed to be ample in size to give a maximum of 7200 b.h.p. They would therefore operate normally on $(4320 \times 100) \div 7200 = 60$ per cent. of their full-load capacity.

"The above-mentioned test, made on a 1500-h.p. double-acting tandem gas engine built by the John Cockerill Company, of Seraing, Belgium, showed a heat consumption of 10,800 B.t.u. per hour per brake horse-power for the engine running at two-thirds of its full-load capacity. According to a curve plotted from the tests, the engine running at 60 per cent. load would show a heat consumption of about 11,100 B.t.u. per hour per brake horse-power. Let it be even 11,500 B.t.u. per hour, at 60 per cent. load of the engine, then the amount of gas required

would be $11{,}500 \div 90 = 128$ cu. ft. per hour per brake horse-power, making the total requirement for blowing engines equal to $4300 \times 128 = 550{,}000$ cu. ft. per hour. This is less than the quantity required at full load by about 170,000 cu. ft. per hour. In other words, 720,000 cu. ft. of gas for the purpose of gas blowing engine is the *maximum* that would ever be required.

AUXILIARY MACHINERY

"The power necessary for lighting the plant, for pumps, hoists, and all the necessary machinery for operating the blast-furnace plant could be assumed to be about 1.5 b.h.p. per ton of pig iron produced per day. This figure will take into account all the modern machinery with which an up-to-date blast-furnace plant is equipped, and is certainly very conservative, as other authorities estimate the auxiliary power to be far less.

"A. Ernst gives the figure of 1 h.p. per ton of pig iron produced; Edward Uehling gives about 1.04 h.p.; W. Oswald, of Coblenz, gives 1 h.p., and the John Cockerill Company about 1.05 h.p. per ton of pig iron produced. At the rate of 1.5 h.p. per ton of pig iron for auxiliary machinery, the total requirements for the blast-furnace plant of 800 tons will amount to $800 \times 1.5 = 1200$ b.h.p. If this power be generated by gas engines, and assuming a gas consumption of 100 cu. ft. per brake horse-power-hour, the total quantity of gas to be deducted for auxiliary power purposes will be $1200 \times 100 = 120{,}000$ cubic feet.

GAS CLEANING

"It has been already indicated that a modern blast-furnace plant will be equipped in the future with extensive gas-cleaning apparatus to cleanse all the gas produced by the furnaces. Aside from the advantage of obtaining a higher temperature in the hot-blast stoves, thus decreasing the quantity of gas necessary for heating the blast and eventually decreasing the coke consumption per ton of pig iron produced, there is a decided advantage in using clean gas for heating the stoves, as the latter do not require to be cleansed as often. This would mean a considerable saving in labor actually expended in the blast-furnace plants for removing the dust which accumulates in a very short time in the flues of the hot-blast stoves. It would even be pos-

sible by using clean gas to do away entirely with the spare hot-blast stoves, thus saving considerably on the first cost of the installation. As the gas-washing apparatus delivers the gas under a pressure of from 3 to 4 in. of water, the size of the conduits for conveying the gas could be decreased for new blast-furnace plants, which again would mean a reduction in the first cost.

"It is a well-known fact that clean gas burns far better than gas containing considerable quantities of very fine dust. In Europe, the centrifugal gas-cleaning apparatus invented by Eduard Theisen is used almost exclusively for gas-cleaning plants. This apparatus requires for a given amount of gas, less power, less water, and less attendance, and is giving far better results than the so-called hydraulic fans which were used six years ago.

"According to the experience as indicated by European practice for cleaning the gas generated by the blast furnaces, it may be assumed that all the gas for our 800-ton blast-furnace plant is to be cleansed in Theisen gas washers of large capacity, to such an extent as not to contain more than about 0.5 g. of dust per cubic meter. The gas for operating gas engines will be subjected to a further cleaning in Theisen gas washers, which will bring down the amount of dust contained in the gas to 0.03 g. per cubic meter (corresponding to 0.0131 grain per cubic foot) or even less. Experience shows that engines using clean gas are able to run six months and more continuously day and night without requiring cleaning internally.

"In order to clean 10,000 cu. ft. of gas per hour to such a degree as to be suitable for hot-blast stoves, Theisen gas washers require about 1.25 h.p. (actual test shows 1.15 h.p.). The power necessary for cleaning the whole quantity of 4,350,000 cu. ft. of gas per hour will therefore amount to 550 brake horse-power.

"As stated before, 30 per cent. of this clean gas goes to the stoves, leaving 70 per cent. to pass through the second series of Theisen gas washers. Gas cleaned for gas-engine purposes in Theisen gas washers requires about 1.5 b.h.p. for each 10,000 cu. ft. of gas per hour (actual tests show only 1.3 brake horse-power.

"The power required for the second series of gas washers will therefore amount to $0.7 \times 435 \times 1.5 = 460$ b.h.p., and total power required for gas-washing purposes will be 1010 b.h.p. Gas-engine dynamos will generate the necessary electric current for operating the electric motors of the gas washers. With a

combined efficiency of 85 per cent., the required capacity of the gas engine will be about 1200 b.h.p., and at the rate of 100 cu. ft. of gas per hour, per brake horse-power, there will be required for gas-cleaning purposes another $1200 \times 100 = 120{,}000$ cu. ft. of gas per hour. Figuring back on the tonnage of pig iron, it will be seen that the power required for gas-cleaning purposes amounts to about 1.5 h.p. per ton of pig iron produced in 24 hours. This figure coincides very nicely with the figure given by W. Oswald, of Coblenz, which is 1.6 h.p. per ton of pig iron produced per 24 hours.

GAS LOSSES

"In the piping for the engines, in the gas engines themselves and in the gas-cleaning plant, about 5 per cent. of the gas required might be lost by leakage, etc. The total loss would therefore amount to $0.05 \times 960{,}000 = 48{,}000$ cubic feet.

"After deducting the quantities of gas necessary for the various purposes of the blast-furnace plant there remains available for other purposes, in round figures, 2,000,000 cu. ft. of gas per hour as shown by Table I. This quantity of gas at the rate of 100 cu. ft. per brake horse-power per hour would provide for 20,000 b.h.p. For each ton of pig iron produced, per 24 hours, there will therefore be available for sale or for other useful work 25 h.p. As found previously, the total quantity of gas generated by two 400-ton furnaces represents over 50 b.h.p. per ton of pig iron produced per 24 hours. Generally speaking, 50 per cent. of the power represented in the gas produced by a blast furnace is available for sale.

TABLE I

	Cubic Feet	Cubic Feet
Total Amount of Gas Produced per Hour........	....	4,350,000
Total Amount to be Deducted, per Hour.........	....	
For Hot Blast Stoves..........................	1,305,000	
For Gas-Blowing Engines......................	720,000	
For Operating Auxiliary Machinery.............	120,000	
For Operating Gas Cleaning Plants.............	120,000	
For Losses in Piping, Engines, etc.............	48,000	
Total..	2,313,000	2,313,000
Am't Available for Other Purposes Outside Blast Furnace Plant Req'm'ts per Hr...............	....	2,037,000

COEFFICIENT OF SAFETY

"Blast furnaces are subject to certain unavoidable irregularities on account of which a 'coefficient of safety' must be introduced in the calculation for determining the available power from a blast furnace of a given capacity. This coefficient is of course extremely variable and depends largely upon the pig-iron market (which might require a banking of the furnaces), upon which the operation of the furnaces, the quality and supply of ore, coke, etc., depend in turn. It is very difficult to foretell how much of the total theoretical available horse-power from the 400-ton furnaces could actually be realized, especially when the electric power generated by using this gas in gas engines is to be sold to outside consumers to whom the delivery of a certain amount of power naturally *must* be guaranteed, perhaps under a heavy penalty. This irregularity in the operation of a blast furnace will have a very great influence on the production of gas, affecting the quantity as well as the quality. With two blast furnaces only it would be perfectly safe to figure on the available horse-power from the gas of one furnace, assuming this coefficient to be 0.5.

"Following the above outlined order of ideas a blast-furnace plant of only two 400-ton furnaces should be equipped in the beginning with a power station of only limited capacity corresponding to the available power from only one furnace, installing later on additional units, if the conditions and operations of the furnace plant would be such as safely to permit the generation of additional electrical power.

ESTIMATIVE CALCULATION FOR AN ELECTRIC POWER STATION OF 10,000 B.H.P. CAPACITY

"The following calculation has been made on the assumption that an electric power plant of about 10,000 b.h.p. is to be installed first. The size of unit best suited for this power plant would be an engine of about 1500 b.h.p. capacity. Seven gas engines of 1500 b.h.p. rated capacity would develop 10,500 b.h.p. In order to meet emergencies an eighth engine as a stand-by or spare unit should be installed, so that the power plant in the beginning would consist of eight 1500-b.h.p. units.

"Generators of 800 kw. would, at the rated load of the gas

engines of 1500 b.h.p., develop about 1000 kw. at 25 per cent. overload. At maximum load of the gas engines of 1650 b.h.p., the generators would carry 1120 kw. each, or 40 per cent. overload. It is evident that 800-kw. generators would perfectly fulfil the requirements, as they easily stand an overload of 25 per cent. for 24 hours and an overload of 40 per cent. for short periods.

"Assuming the complete equipment of the power plant to consist of eight double-acting tandem gas engines with cylinders 38 in. diameter by 54 in. stroke, speed 85 r.p.m., with a rated load of 1750 indicated horse-power, or 1500 b.h.p. each, direct-connected to alternators of 800 kw. giving three-phase currents at 25 cycles and 6600 volts, with exciters, switchboard and wiring; gas-cleaning plant for power station only, complete piping, air-compressor outfit, buildings, foundations, and traveling crane; the cost of the plant will be as shown in Table II.

TABLE II

COST OF INSTALLATION OF POWER PLANT

Item	Weight, Pounds	Cost
Gas Cleaning Plant	250,000	$33,500
Building and Foundation for Same	....	6,500
Ring Gas Main	100,000	6,000
Building for Eight Gas Engines and Dynamos	....	45,000
Foundation for Engines	....	26,000
Traveling Crane	120,000	8,500
Eight Gas Engines	4,000,000	424,000
Complete Piping	470,000	24,000
Air Compressor Outfit	40,000	5,000
Complete Electrical Equipment	670,000	162,500
Total Weight of Machinery	5,650,000	
Total Cost of Installation	....	$741,000
Cost of installation per B. H. P. (Total Capacity 12,000 B. H. P.)	....	61.60
Cost of Installation per K. W. (Total Capacity 8,300 K. W.)	....	89.50

GAS-CLEANING PLANT

"The part of the gas-washing plant chargeable to the power house has to clean a maximum of 12,000 × 100 = 1,200,000 cu. ft. of gas per hour, or 20,000 cu. ft. per minute, provided that all eight gas engines are in operation under full load. This quantity

of 20,000 cu. ft. of gas per minute, which has previously been cleaned with the bulk of the gas of the furnaces, can be cleaned by a gas-washing plant consisting of four Theisen gas washers No. 3, capable of cleaning an average of 6000 cu. ft. of gas per minute each. A spare Theisen apparatus is not necessary, as in case of a shut-down of one washer for cleaning or repairs, the three remaining washers will easily take care of the total quantity of gas. Each Theisen apparatus would be directly coupled to a 70-h.p. electric motor running at a speed of about 450 revolutions per minute.

"Between the gas main and the Theisen apparatus, there should be inserted a pressure regulator which automatically shuts off the entrance of gas to the cleaning plant in case of a lack of gas, thus avoiding a vacuum in the main gas conduit, and consequently preventing the entrance of air into the latter, which might produce dangerous explosive mixtures in the pipe line. The gas-pressure regulator and the four Theisen gas washers could be arranged in such a way that by the simple manœuvering of a few valves, the gas can be "by-passed" at the pressure regulator of each Theisen apparatus, thus permitting the cleaning or repairs of the latter without interfering in the least with the operation of the power plant. Each Theisen apparatus would deliver the clean gas into the water separator in front of the gas washer. These separators take out the water from the gas and deliver clean, cool, and dry gas into a collecting pipe which, in turn, is connected to the ring gas main.

"A light steel-frame building with brick walls and solid roof is sufficient to shelter the Theisen gas washers, their motors and the water separators. This building would be about 100 ft. long and 30 ft. wide, and should be provided with a traveling crane of 5 tons capacity and 30 ft. span.

GAS MAIN

"Surrounding the engines and in the building there should be installed a ring gas main, of about 4 ft. diameter, from which the engines take their supply of gas. This ring conduit avoids all possible interference between the gas streams leading to the various engines and secures a uniform supply of gas. No connection between this gas main and the gas-cleaning plant has been

considered in this estimate, as it depends upon the local conditions and arrangements.

BUILDING FOR GAS ENGINES

"The building for the gas engines would be about 85 ft. wide and 250 ft. long. It should be a steel structure with brick walls and slate roof, with hardwood floor and provided with runways for the electric traveling crane. Each 1500-h.p. gas engine requires for its foundation about 10,000 cu. ft. of concrete. The price as given in Table II includes foundations for the eight engines and all the iron work, such as foundation-bolt washers, girders, supports for piping, etc.

"An electric traveling crane of about 25 tons capacity and about 85 ft. span, with main and auxiliary trolley, would be required.

GAS ENGINES

"The price as given for the gas engines includes all the necessary auxiliary apparatus, such as electrically driven barring-over devices, pumps operated by the main shafts of the engines for the circulation of water under pressure through pistons and piston rods, complete piping, etc. It also includes governors having special hand-operated regulating devices for synchronizing the engines, and fly-wheels of sufficient size, combined with the revolving elements of the generators, to assure sufficiently close regulation to synchronize and run the generators in parallel without difficulty.

"The price of complete piping, as given in Table II, covers all the piping for gas, air, exhaust, compressed air and water inside of the engine building, and connections to the gas main, and also includes two exhaust mufflers with stacks and compressed-air tank on each engine.

"The air-compressor outfit would consist of two electrically driven two-stage air compressors, each having a capacity of 150 cu. ft. of free air per minute, compressing against 150 lb. to the sqare inch. A main compressed-air reservoir with safety valve and gages is included in the price. The capacity of each air-compressor outfit would be ample to permit the simultaneous starting of two engines.

"The electrical equipment would comprise eight 800-kw. alternating-current generators, two exciter units, driven independently, the switchboard and the complete wiring between generators and switchboard.

OPERATING COST OF POWER PLANT

"The operating cost of the power plant consists of:

"(*a*) Fixed charges, comprising the interest of the money invested in the plant, depreciation and maintenance of various items, insurance and taxes.

"(*b*) The cost of water consumed for washing and cooling purposes.

"(*c*) Cost of oil and grease.

"(*d*) Expenditures for repairs on gas-cleaning plant, engines, piping, and electrical equipment.

"(*e*) Expenditure for wages and salaries.

"(*f*) Cost of fuel.

"The computation of the operating cost of power plant has been made for three different assumptions:

"First, the power plant running at full-load capacity; output 10,500 b.h.p. = 70,080,000 brake horse-power-hours, or 63,510,000 kilowatt-hours per year.

"Second, power plant running at three-quarter load; output 8000 b.h.p. = 70,080,000 brake horse-power-hours, or 48,180,000 kilowatt-hours per year.

"Third, power plant running at half-load capacity; output 5000 b.h.p. = 43,800,000 brake horse-power-hours or 31,536,000 kilowatt-hours per year.

"One year = 365 days; one day = 24 hours.

(*a*) FIXED CHARGES

"Table III gives the various items of fixed charge.

TABLE III

FIXED CHARGES

ITEM	Cost	Interest %	Depreciation %	Insurance %	Total %	Life of Plant Years	Total per Annum
Gas Cleaning Plant	$33,500	5	10	1	16	8.31	$5,360
Building and Foundations	6,500	5	4	1	10	16.62	650
Ring Gas Main	6,000	5	5	1	11	14.21	660
Buildings for Eight Gas Dynamos	45,000	5	4	1	10	16.62	4,500
Foundations for Engines	26,000	5	4	1	10	16.62	2,600
Traveling Crane	8,500	5	5	1	11	14.21	930
Gas Engines	424,000	5	8	1	14	9.95	59,360
Complete Piping	24,000	5	5	1	11	14.21	2,640
Air Compressor Outfit	5,000	5	5	1	11	14.21	550
Complete Electrical Equipment	162,500	5	8	1	14	9.95	22,750
Totals	741,000	5		0	13.5		100,000

Fixed Charges per Kilowatt Hour at Full Load . . . . 0.1575 cents
" " " " " " ¾ Load . . . . 0.2076 cents
" " " " " " ½ Load . . . . 0.3171 cents

(*b*) WATER REQUIRED

"*Full load.* — For cleaning 1000 cu. ft. of gas per minute, the Theisen gas-cleaning apparatus requires a maximum of 12 gal. of water. The part of the gas-cleaning plant chargeable to the power house has to clean a maximum of 12,000 × 100 = 1,200,000 cu. ft. of gas per hour or 20,000 cu. ft. per minute, requiring 240 gal. per minute, or 345,600 gal. per day.

"At full load, the gas engine will consume about 8.5 gal. of water per hour per brake horse-power. At 10,500 b.h.p. rated capacity of power plant, the requirements of cooling water will be 89,250 gal. per hour or 2,142,000 gal. per day, or say 2,154,400 gal. per day. Total quantity of water per day, 2,500,000 gallons.

"The blast-furnace plant being supposed to be located near a stream of water, the cooling water could be provided from the pumping station of the plant at a very low cost of pumping, say at 2 cents per 1000 gal. At this rate, the total expenditure for water per day would be $50. The total cost of water per kilowatt-hour at full load would be 0.02874 cent.

"*At three-quarter load* the gas-washing plant will require about 14 gal. of water per 1000 cubic foot of gas per minute. As previously stated, the heat consumption of the gas engines running at three-quarter load will amount to 10,000 B.t.u. per brake horse-

power, or, in other words, 1 brake horse-power-hour will require 112 cu. ft. of gas. The output of the power plant being 8000 b.h.p. at three-quarter load, the total gas consumption per hour will amount to 896,000 cu. ft. or, say, 15,000 cu. ft. of gas per minute. The quantity of washing water for cleaning this quantity of gas will be 14 x 15 = 210 gal. per minute, or 12,600 gal. per hour, or 302,400 gal. per day.

"The consumption of cooling water at three-quarter load will amount to 10.5 gal. per hour per brake horse-power; therefore 8000 b.h.p. will require 84,000 gal. per hour or 2,016,000 gal. per day. The total quantity of water per day, therefore, will be 2,318,400 gal., say in round figures 2,320,000 gallons.

"*At one-half load,* the total expenditure for water for cooling and washing purposes will amount to $46.40 per day. Cost of water per kilowatt-hour at three-quarter load, 0.03514 cent.

"*At one-half load* the consumption of washing water for the Theisen gas washers will amount to 16 gal. per 1000 cu. ft. of gas cleaned per minute. The consumption of the gas engines, as previously stated, will be 12,600 B.t.u. per hour per brake horse-power, or 1 brake horse-power-hour will require 140 cu. ft. of gas. The total quantity of gas consumed will be 700,000 cu. ft. per hour or about 11,700 cu. ft. per minute. The amount of washing water will therefore be 187.2 gal. per minute or 11,232 gal. per hour, making, per day, 269,568, say 270,000 gallons.

"The consumption of cooling water at one-half load amounts to 13 gal. per brake horse-power-hour, requiring 65,000 gal. per hour or 1,560,000 gal. per day. The total quantity of water for the power plant, therefore, will be 1,830,000 gal. per day. At the rate of 2 cents per 1000 gal. the total expenditure for water per day will amount to $36.60. Cost of water per kilowatt-hour at one-half load, 0.04236 cent.

(*c*) OIL AND GREASE REQUIRED

"*Full load.* — According to actual performance of large gas-engine power plants, the plant of 10,500 b.h.p. in operation, including electrical equipment and auxiliary machinery, such as Theisen apparatus, air compressors, etc., will not consume more than 2 g. of lubricants per brake horse-power-hour, 1.2 g. of which will be cylinder oil at 35 cents per gallon and 0.8 g. of which will be engine oil at 20 cents per gallon. The total expenditure per

year will, therefore, amount to $15,645. Cost of oil and grease per kilowatt-hour at full load, 0.02460 cent.

"*At three-quarter load* the quantity of lubricants required will not be very much less than at full-load capacity; in any event it might be assumed that the total expenditure will be about 10 per cent. less per year than at full-load capacity of the plant. The cost of lubrication of the power plant will therefore amount to $14,080 per year, and the cost per kilowatt-hour at three-quarter load will be 0.02922 cent.

"*At half load* about 15 per cent. might be deducted from the cost of lubrication for the power plant when running at full-load capacity, as at an almost constant load factor of 0.5 several engines would be shut down. The total expenditure per annum for lubrication of power plant running at half load would therefore amount to $13,300. Cost of oil and grease per kilowatt-hour at half load, 0.04219 cent.

(*d*) REPAIRS ON MACHINERY

"Although the item depreciation and maintenance of the gas-power plant covers certain repairs on the machinery, and as small repairs would have to be made by the operating personnel inside of their regular working hours, it is usual to figure on a separate item for repairs on machinery, providing for accidents which might require the replacing or repairing of certain parts of the machinery. Experience with large power plants in Europe indicates that repairs of this kind do not exceed about 2½ per cent. per year of the purchase price of the gas engines and generators. For the gas-cleaning plant, 7 per cent. per year of the purchasing price may be assumed, while for the air compressor 5 per cent., and for piping and crane 2 per cent. per year of the respective purchasing prices will cover necessary repairs on these items.

"*At full load,* the total expenditure for repairs on the power-plant equipment will thus amount to about $18,000 per year. Cost of repairs per kilowatt-hour, 0.02834 cent.

"*At three-quarter load,* as the machinery is less strained, a certain percentage of the expenditure for repairs per year for full-load capacity of power plant might be deducted. Assuming that this reduction may amount to about 10 per cent., the total cost of repairs per year will amount to about $16,800. Cost of repairs per kilowatt-hour, 0.03362 cent.

"*At half load,* a deduction of about 15 per cent. of the cost of repairs at full-load capacity of power plant may properly be applied, so that the expenditure per annum for the plant running at half load will amount to approximately $15,300. Cost of repairs per kilowatt-hour at half load, 0.04852 cent.

(*e*) WAGES AND SALARIES

"*Full load.* — The power plant when running at its full-load capacity will require the following attendants:

	PER CENT.
1 Chief engineer	$3,000
1 Assistant	1,800
8 Machinists at 30c. per hour, for gas engines only	10,513
10 Helpers at 21c. per hour	9,198
2 Machinists at 25c. per hour, for gas-cleaning plant and compressors	2,190
4 Dynamo tenders at 22.5c. per hour	3,942
4 Switchboard tenders at 20c. per hour	3,504
1 Bookkeeper and clerk	1,200
Total per year	$35,346

Say, in round figures, $35,350 per year.

"Wages and salaries per kilowatt-hour, at full load, 0.05566 cent.

"*At three-quarter load.* — Not much money could be saved in wages and salaries for the power plant when the latter is running at three-quarter load; possibly one dynamo tender and one switchboard tender could be dispensed with, so that the total expenditure for wages and salaries per annum would amount to $33,500. Cost of wages and salaries per kilowatt-hour, at three-quarter load, 0.06953 cent.

"*At one-half load,* one dynamo tender, one switchboard tender, and two helpers could be dispensed with, so that the total expenditure for wages and salaries per year would amount to $31,600. Wages and salaries per kilowatt-hour at half load, 0.10020 cent.

(*f*) FUEL

"It is generally assumed in computations determining the operating cost of a blast-furnace gas-power plant that the blast-furnace gas has no value, so that the cost of fuel is generally omitted in such calculations. This, perhaps, might have been permissible formerly when the blast-furnace gas was used in the condition in which it left the standard dry-dust catchers, con-

taining immense quantities of dust and thereby restricting considerably the field of utilization.

"In modern blast plants, however, all the gas will be subjected to a thorough cleaning process, which entails certain expenditures for installation, power, maintenance, and attendance for the gas-cleaning plant. It is, therefore, only fair to appraise the blast-furnace gas which is used for operating gas engines.

"Modern double-acting tandem gas engines will develop 1 b.h.p. on 9000 B.t.u. or 100 cu. ft. of gas, at full load; 10,000 B.t.u. or 112 cu. ft. of gas, at three-quarter load, and 12,600 B.t.u. or 140 cu. ft. of gas, at half load.

"Assume that the price of coal delivered into bins at the plant is \$2.75 per ton, that the coal has a heat value of 13,000 B.t.u. per pound, and, further, that steam of 150 lb. gage pressure is raised by burning this coal under boilers. One pound of steam will then contain 1225 B.t.u. above 0 deg. F. Assuming feed water at 70 deg., there would be required 1155 B.t.u. to generate 1 lb. of steam of 150 lb. gage pressure. In a boiler plant having 65 per cent. efficiency, 1000 lb. of coal could raise 7300 lb. of steam, the value of which would be $2.75 \div (2 \times 7.3) =$ \$0.188, or 18.8 cents. To this must be added for labor and maintenance approximately 1 cent per 1000 lb. of steam, making the total value of 1000 lb. 19.8 cents. One thousand cubic feet of blast-furnace gas has a heat value of $1000 \times 90 = 90{,}000$ B.t.u., and is therefore equivalent to $(0.65 \times 90{,}000) \div 1155 = 51$ lb. of steam, which in turn is worth $51 \times 19.8 \div 1000 = 1$ cent. The value of 1000 cu. ft. of blast-furnace gas would, therefore, be 1 cent.

"Another way of determining the value of blast-furnace gas would be to compare it with natural gas, 1000 cu. ft. of which has a heat value of 900,000 B.t.u. At 10 cents per 1000 cu. ft. for natural gas, the value of 1000 cu. ft. of blast-furnace gas would be $90{,}000 \div 900{,}000 \times 10 = 1$ cent.

"*Full load.* — One thousand cubic feet of blast-furnace gas will, at the rate of 100 cu. ft. per brake horse-power-hour, develop at full load 10 brake horse-power-hours. The value of the blast-furnace gas consumed per brake horse-power-hour will therefore be 0.1 cent. Fuel per kilowatt-hour at full load, 0.1448 cent.

"*At three-quarter load,* the gas consumption of the plant will be 112 cu. ft. per brake horse-power per hour; the value of which is 0.112 cent. Fuel per kilowatt-hour at three-quarter load, 0.1629 cent.

"*At half load* the gas consumption amounts to 140 cu. ft. per brake horse-power-hour, the value of which is 0.14 cent. Fuel per kilowatt-hour 0.1944 cent.

"With coal at $3.25 a ton, 1000 lb. of steam at 150 lb. boiler pressure would be worth 23 cents. The value of 1000 cu. ft. of blast-furnace gas would then be $(0.65 \times 90{,}000 \times 23) \div (1155 \times 1000) = 1.173$ cents. Compared with natural gas of 900 B.t.u. per cubic feet the value of the blast-furnace gas would correspond to a price of 11.73 cents per 1000 cu. ft. of natural gas. Tables IV, V and VI give a summary of the cost of operation

TABLE IV

Operating Cost of Power Plant at Full Load

Item	Per K. W. Year	Per K. W. Hour Cents	Per B.H.P. Year	Per B.H.P. Hour Cents
Fixed Charges	$13.793	0.15745	$9.524	0.10871
Water	2.518	0.02874	1.783	0.01984
Oil and Grease	2.155	0.02460	1.490	0.01700
Repairs	2.483	0.02834	1.714	0.01957
Wages and Salaries	4 876	0.05566	3.366	0.03843
Total without Value of B. F. Gas	25.825	0.29479	17.877	0.20355
In Round Figures	$25.83	0.295 ¢	$17.88	0.204 ¢
Fuel Equivalent to Coal @ $2.75	12.69	0.145	8.76	0.100
Total	$38.52	0.440 ¢	$26.64	0.304 ¢
Fuel Equivalent to Coal @ $3.25	4.89	0.170	10.28	0.117
Total	$40.72	0.465 ¢	$28.16	0.321 ¢

TABLE V

Operating Cost of Power Plant at Three-quarter Load

Item	Per K.W. Year	Per K.W. Hour Cents	Per B.H.P. Year	Per B.H.P. Hour Cents
Fixed Charges	$18.182	0.20755	$12.500	0.14269
Water	3.078	0.03514	2.116	0.02416
Oil and Grease	2.560	0.02922	1.760	0.02009
Repairs	2.945	0.03362	2.025	0.02312
Wages and Salaries	6.091	0.06953	4.187	0.04780
Total without Value of B. F. Gas	32.856	0.37506	22.588	0.25786
In Round Figures	$32.86	0.375 ¢	$22.59	0.258 ¢
Fuel Equivalent to Coal @ $2.75	14.27	0.163	9.81	0.112
Total	$47.13	0.538 ¢	$32.40	0.370 ¢
Fuel Equivalent to Coal @ $3.25	16.74	0.191	11.51	0.131
Total	$49.60	0.566 ¢	$34.10	0.389 ¢

TABLE VI

OPERATING COST OF POWER PLANT AT ONE-HALF LOAD

ITEM	Per K.W. Year	Per K.W. Hour Cents	Per B.H.P. Year	Per B.H.P. Hour Cents
Fixed Charges	$27.777	0.31709	$20.000	0.22831
Water	3.711	0.04236	2.672	0.03050
Oil and Grease	3.690	0.04219	2.660	0.03036
Repairs	4.250	0.04852	3.060	0.03493
Wages and Salaries	8.777	0.10020	6.320	0.07215
Total without Value of B. F. Gas	48.205	0.55036	34.712	0.39625
In Round Figures	$48.21	0.550 ¢	$34.71	0.396 ¢
Fuel Equivalent to Coal @ $2.75	17.03	0.194	12.26	0.140
Total	$65.24	0.744 ¢	$46.97	0.536 ¢
Fuel Equivalent to Coal @ $3.25	19.97	0.228	14.38	0.164
Total	$68.18	0.778 ¢	$49.09	0.560 ¢

for each item for full load, three-quarter load and one-half load capacity of the power plant, and Fig. 144 shows curves plotted from these tables.

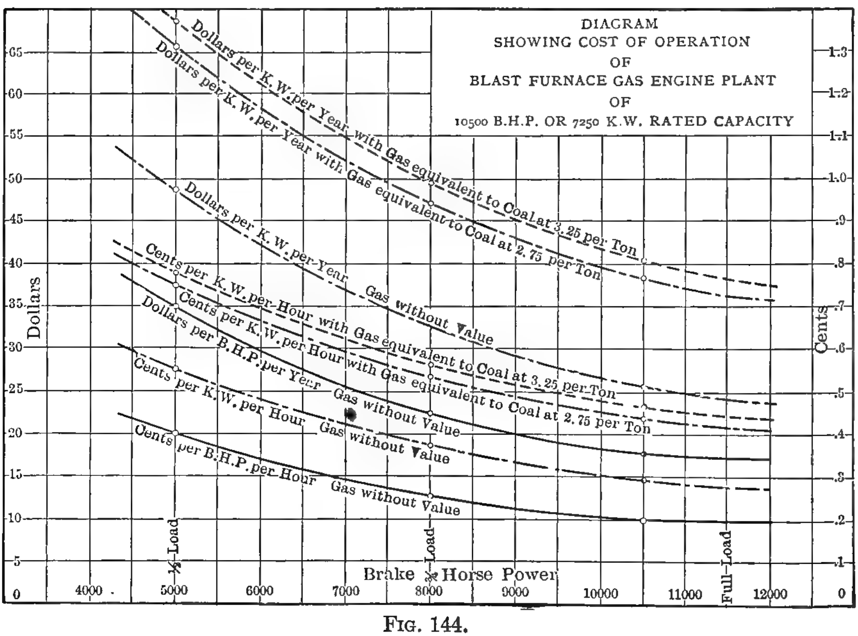


FIG. 144.

CONCLUSIONS AS TO COST

"From the foregoing computations it will be evident that a power plant of about 10,500 b.h.p. capacity, complete in every detail and installed in connection with a blast-furnace plant, would be capable, when running at full-load capacity, of producing 1 b.h.p. one year at the low cost of $17.88, no value being placed on the blast-furnace gas. The enormous saving as compared with the production of power in a steam-engine plant is still more striking when the cost of generation of the electric current is considered. According to the accompanying tables, 1 kilowatt-hour at full-load capacity of the plant could be produced at 2.95 mills, which is away below the best figure ever reached with a steam-engine power plant. Even under worse conditions, that is, when the power plant is running on an average of only 50 per cent. of its total capacity, the cost of generation of 1 kilowatt-hour is but 5.50 mills.

"It is evident that an eventual increase in the capacity of the power plant would tend to reduce the cost of the generation of power per unit, as certain expenditures for the power plant of 10,500 b.h.p. would remain unchanged for additional power units.

DATA FROM ACTUAL OPERATION IN THE JOHN COCKERILL COMPANY, SERAING, BELGIUM

"Computations of this character are sometimes considered as being 'theoretical,' as they naturally can only be made by making certain assumptions. That such figures have some practical value, inasmuch as they permit the clear understanding of the results of practical experience, accounting for the make-up of these figures, will be appreciated by studying the diagrams in Fig. 145 which give actual figures obtained in the works of the John Cockerill Company. This company has in operation at present seven blast furnaces of about 1200 tons daily capacity, and in addition large steel plants, rolling-mill plants, coal and ore mines, coke ovens, boiler shops, machine shops, bridge works, gunnery works, steam-turbine works, locomotive works, etc. The company employs about 15,000 workmen.

"In the first diagram, the power consumption for the past five years is shown. It will be seen to what extent the use of elec-

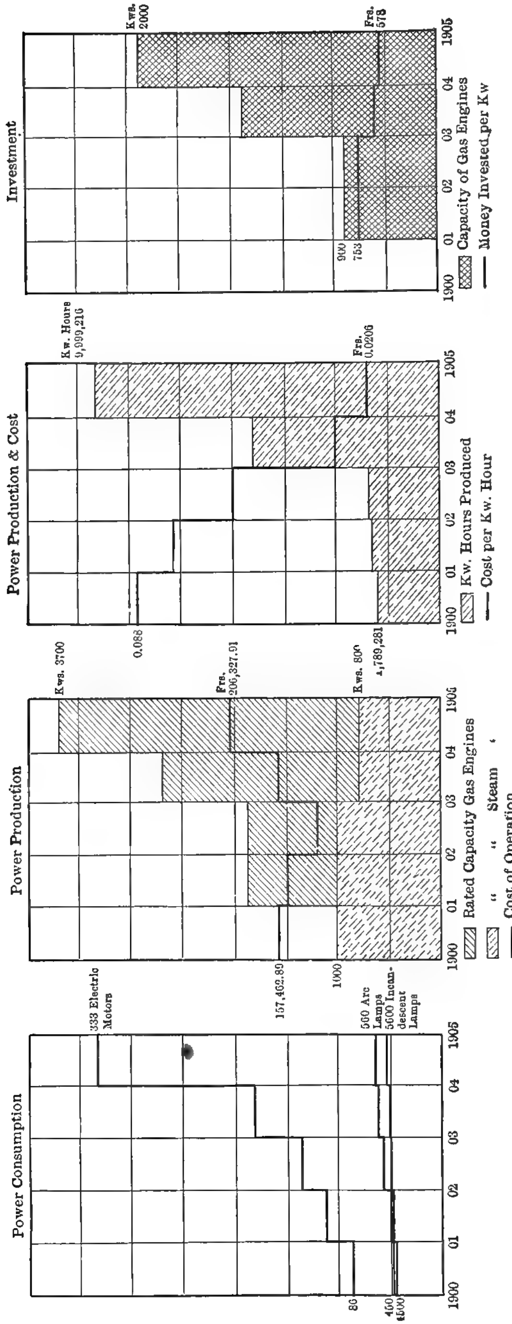


FIG. 145. — Diagrams Showing Evolution of Power Distribution, Cost and Investment in the John Cockerill Works, Belgium.

tricity for the various purposes has been developed inside of five years. In 1900 the Cockerill Company had 86 electric motors in use, while in 1905 the number of motors amounted to 333. The lighting outfit consisted in 1900 of 450 arc and 4500 incandescent lamps, whereas in 1905 the corresponding figures were 660 arc and 5600 incandescent lamps. In order to produce the power for the electric service 1000 kw. in steam engines were installed in 1900, as shown in the diagram. In 1901, the first gas engines operating direct-current generators of 900 kw. total capacity were installed; in 1903, 900 kw. in gas engines were added and the capacity of the steam-engine plant was decreased 200 kw., so that up to 1905 only 800 kw. in steam engines were in operation; in 1904, more gas engines were added, bringing the total capacity of the power plant up to 3700 kw. This diagram shows that inside of five years the capacity of the power plant has been increased 370 per cent.

"The most interesting feature of this diagram is the line showing the cost of operation of the power plant. In 1900 the total operating cost for 1000 kw. in steam engines amounted to 157,462.88 francs; in 1905, for the total capacity of the power plant of 3700 kw. the cost of operation amounted to 206,327.91 francs. The increase in the operating cost, therefore, amounted to 31 per cent. only, whereas the capacity of the power plant had been increased 370 per cent.

"The third diagram shows that the output of kilowatt-hours produced per year increased from 1,789,281 in 1900 to 9,999,216 in 1905. The cost per kilowatt-hour fell from 0.088 franc in 1900 to 0.0206 franc in 1905, so that the cost of 1 kilowatt-hour in 1905 was but 25 per cent. of the corresponding cost in 1900.

"The fourth diagram of the series shows the capacity of the gas engines and the amount of money invested per kilowatt. In 1901, when only 900 kw. in gas engines existed, 753 francs were tied up per kilowatt. In 1905, when the total capacity amounted to 2900 kw. in gas engines, the money invested per kilowatt was only 578 francs.

"Although the results as indicated in these diagrams could not be used for a direct comparison with blast-furnace plants in this country, on account of the considerable difference in the general conditions of operation, cost of labor, etc., so that it would not

be of any advantage to transpose the operating cost per kilowatt-hour into American money (0.0206 franc would correspond to 0.415 cent), the striking showing of these diagrams, for which I am indebted to Mr. Leon Greiner, chief electrician of the John Cockerill Company, proves conclusively that great benefit could be derived from the installation of gas engines for the various power purposes in a modern blast-furnace plant."

Following is an abstract from the valuable paper, "The Blast Furnace as a Power Plant," by Edward A. Uehling, who deals with the subject from the standpoint of the metallurgical engineer.

The Blast Furnace as a Producer of Gas

"In the process of reducing iron from its ores in modern blast-furnace practice the constituents of the resulting gas have their origin in the ore, the flux, the fuel and the blast. Carbon, the oxidation of which provides the heat necessary to effect the reductions, enters the furnace in the charcoal, coal, or coke employed as a fuel, and also in the flux, chemically combined with calcium and oxygen to form calcium carbonate, $CaCO_3$.

"The oxygen required to oxidize this carbon is found, first, in chemical combination with the various metalloids composing the ore, which in the order of their importance are the oxides of iron, Fe_2O_3, silicon, SiO_2, phosphorus, P_2O_5, manganese, Mn_3O_4, and sulphur, SO_3; second, in the air and moisture supplied by the blast; and third, in the calcium carbonate, $CaCO_3$, flux employed to make a liquid slag. The above oxides in the presence of an excess of incandescent carbon, as is the case in blast-furnace work, are reduced and evolve carbon monoxide, CO, as indicated by the following formula:

$$\begin{aligned}
Fe_2O_3 &+ 3C = 2Fe + 3CO \\
SiO_2 &+ 2C = Si + 2CO \\
P_2O_5 &+ 5C = 2P + 5CO \\
Mn_3O_4 &+ 4C = 3Mn + 4CO \\
SO_3 &+ 3C = S + 3CO
\end{aligned}$$

"Aside from the fixed carbon in the fuel, which in the case of coke may be assumed to be about 85 per cent., there will be about 2 per cent. of volatile hydrocarbons, and a variable amount of water vapors which enter into the composition of the gas.

"Aside from the oxygen introduced in the blast there will be a small amount of hydrogen, dependent upon the per cent. moisture in the atmosphere, which also enters into the composition of the gas.

"In the United States practice about 2 per cent. of the fuel consumed in blast-furnace work is charcoal, from 6 to 8 per cent. anthracite coal, and from 90 to 92 per cent. is coke.

"The average amount of coke required per gross ton of pig iron is between 1600 and 3600 lb., varying with the quality of the coke, the economy of the plant, and the grade of pig iron produced.

WEIGHT OF GAS PER TON OF PIG IRON

"In the following discussion the amount of iron ore dealt with is sufficient to produce 2240 lb. of pig iron of average composition. The fuel is 2000 lb. of coke having 85 per cent. of fixed carbon; the flux 1200 lb. of limestone, calcium carbonate; and the air supplied by the blast contains 1 per cent. of moisture, which may be taken as an average for the year around.

"The chemical reactions taking place in a blast furnace in which the constituents of the charge are in the above proportion can best be followed by reference to the diagram shown in Fig. 146. Starting with the iron ore the number of pounds of oxygen available from the various constituents are as follows:

Fe_2O_3	(93.5 per cent.)	897.60 lb.
Mn_3O_4	(0.8 per cent.)	6.95 lb.
SiO_2	(1.5 per cent.)	29.40 lb.
P_2O_5	(0.45 per cent.)	13.00 lb.
SO_3	(0.05 per cent.)	1.68 lb.
Total weight of O from ore to produce one ton pig iron		948.63 lb.

"From 1200 lb. of calcium carbonate flux, 698.4 lb. enter the slag as CaO, and 501.6 lb. of CO_2, or 136.8 lb. of carbon and 364.8 lb. of oxygen, are available for the production of gas.

"Of the 2000 lb. of coke fuel used per ton of pig iron produced, 85 per cent., or 1700 lb., is assumed to be fixed carbon. Of this amount one-half of 1 per cent., or 8.5 lb., is assumed to be wasted by being blown out with the gas, and 3.75 per cent. of 2240 lb., or 84 lb., is absorbed by the iron, which leaves 1607.5

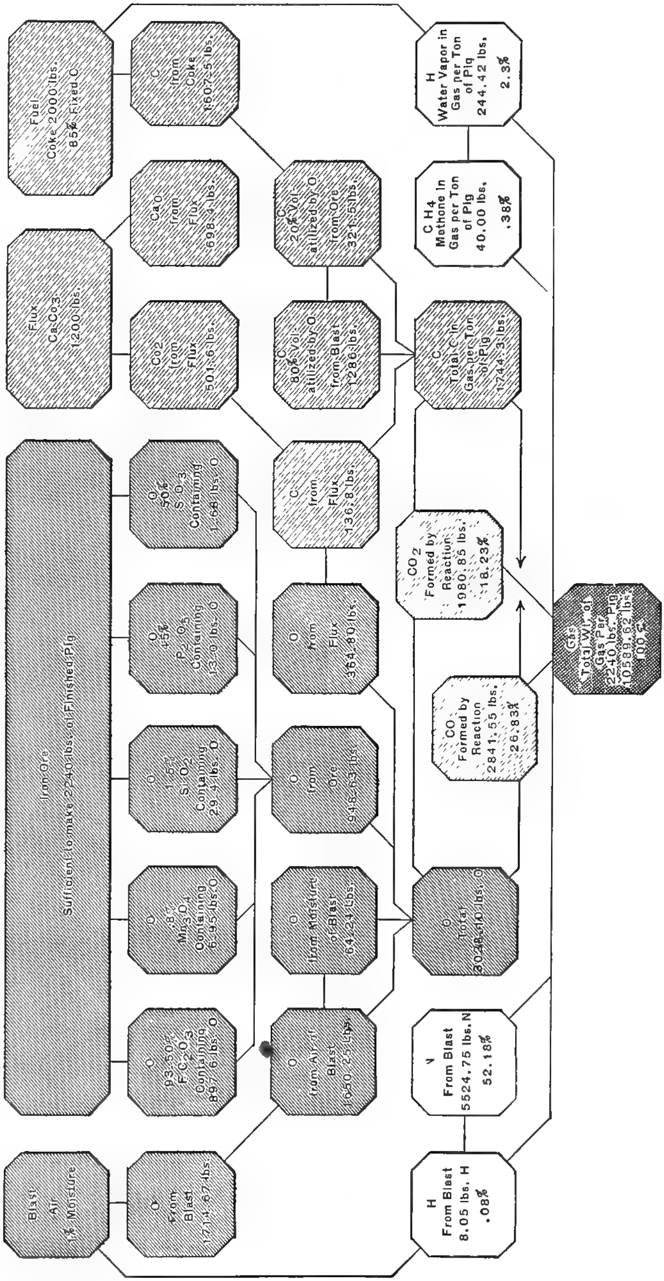


FIG. 146. — Diagram Showing Chemical Reactions Taking Place in a Blast Furnace (Uehling).

lb. to be gasified by oxidation in the process of smelting. Of this amount on an average 80 per cent. is assumed to be oxidized by the oxygen from the blast, and the remaining 20 per cent. by that liberated from the ore and flux in the process of reduction. Adding the amounts of oxygen and carbon available from the various sources gives a total of 3028.1 lb. of oxygen and 1744.3 lb. of carbon. Besides these two principal constituents, 40 lb. of methane gas and 244.42 lb. of water vapor come from the coke and 8.05 lb. of hydrogen and 5524.75 lb. of nitrogen from the blast. The sum of these six constituents is 10,589.62 lb., the total weight of gas produced in the blast furnace in the making of 1 ton of pig iron.

"A sufficient amount of the oxygen constituent will first combine with the carbon to convert it all into carbon monoxide, and the remaining amount will oxidize a part of the carbon monoxide to carbon dioxide, the chemical reactions taking place according to the following formula, in which the numerals represent molecular weights or relation of the weights in which the respective elements will combine.

$$12C + 16O = 28CO.$$
$$28CO + 16O = 44CO_2.$$

"The total amount of the two gases formed in the furnace, based on the foregoing assumptions, is 2841.55 lb. of CO and 1930.85 lb. of CO_2.

"The calorific value of the resulting blast-furnace gas is:

$$\begin{aligned} 26.83 \text{ per cent. CO} &+ 4{,}331.\text{ B.t.u.} = 1162.00 \text{ B.t.u.} \\ 0.08 \text{ per cent. H} &+ 51{,}717.\text{ B.t.u.} = 41.38 \text{ B.t.u.} \\ 0.38 \text{ per cent. } CH_4 &+ 20{,}975.\text{ B.t.u.} = 79.70 \text{ B.t.u.} \end{aligned}$$

or 27.29 per cent. combustible matter furnishes 1283.08 B.t.u. per pound of gas, or 13,587,330 B.t.u. per ton of pig iron smelted.

"On the assumption that the blast carrying 1 per cent. moisture enters the stoves at 100 deg. and is heated to 1200 deg., and that the air and gas enter the combustion chamber at a temperature of 60 deg. and the products of combustion escape at 460 deg., the amount of gas required to heat the blast per ton of pig produced is 1884.38 lb. The total gas produced per ton of pig being 10,589.6 lb., the amount of gas available for the pro-

duction of power is 8705.24 lb., which, on the basis of a value of 1283 B.t.u. per pound and an absolute thermal efficiency of 25 per cent. for the gas engine, is equivalent to 1097.76 h.p. per ton of pig produced per hour. Of this amount, if 250 h.p. per ton of pig iron produced per hour are used for the operation of blowing engines, pumps, etc., there will be available for outside power 1097 — 250 = 847 h.p. per 2240 lb. of finished pig produced per hour.

"Comparing the total amount of power produced in the gas engine with the total amount of coke used, we find that without charging any of the fuel to the process of smelting, 1 h.p. is available for every 1.82 lb. of coke consumed."

Attitude of the American Iron Industry toward the Gas-power Problem

"Enough has been established," says the *Iron Age*, "by the history of recent years to satisfy the iron trade that tearing down and rebuilding on a new scale, and the establishment of new standards of efficiency, which are the continuing order in all departments of modern industry and engineering, will make the demands upon the iron and steel works greater and greater." This fashion in every line of discarding the old, not because it is worn out, but because something better has been devised to do the work, and of applying every year a large part of the wealth taken from the ground to the replacement of the equipment with which the country does the work, is a specific and predominant feature characterizing American industrial progress, which is not equaled anywhere in the world.

The vast and continuously increasing demand for iron and steel must be accompanied, inevitably, (1) by the growing difficulty to find suitable ores in sufficient quantities and qualities, and at convenient distances from the fuel supply; (2) by an increase in the weight of coke that must be charged at the furnaces together with the ores for smelting the latter; (3) by a rise in the cost of production, owing to the higher prices that must be paid for ores, fuels, and labor.

Therefore the productive efficiency of iron and steel works, especially of those independent works that do not control the transportation factor, and their capability to compete with other pro-

ducers will in future, more than ever before, depend on the right husbanding and on the proper valuation of the raw materials, fuels and by-products of the plant. Great savings in operating cost can be realized through the judicious utilization of waste gases and waste coals and their application for a variety of purposes within the works, for which at present costly boiler and furnace coal must be bought.

On the other hand, the earning capacity of iron and steel works can be greatly increased by adding to the remunerative returns from the finished goods those yielded by the waste gases and low grade coals when sold as heat or light or power to outside consumers in the neighboring districts.

The only means that have been devised so far for obtaining proper utilization, that is, for covering all inside requirements from the available gases and other waste and, besides, retaining a large amount available for more profitable usage outside, consist in the application of large gas engines in the central station. This mode of operation enables one, owing to the economic generation of electric current, both to employ electric drive all over the works, thereby securing maximum economy of operation, and to distribute the remaining energy to neighboring industrial centers at a profit.

That the responsible quarters of the American iron industry are getting wide awake to the importance of the gas-power problem can best be seen when reading over the remarkable words which Dr. R. W. Raymond, secretary of the American Institute of Mining Engineers, addressed to a recent meeting of the Iron and Steel Institute, in London:

"In spite of the wealth of our rich ores, our half-developed mineral resources, and our youthful strength as a nation, we are beginning to learn that heat and the materials that yield heat must be economized. We are not so rich that we can go on wasting, and if we succeed at all in maintaining the position to which we have somewhat suddenly jumped in this branch of industry, it must be done by carrying our bookkeeping out to the third place of decimals, . . . and by saving as well as spending. I may say for American metallurgists and their great individual or corporate combinations of capital, that they have not only heaped up sums in investments which staggered the imagination, but have also made a single dollar go further by putting a great many in-

dividual dollars together — which is indeed the only justification for our large accumulation of capital. Moreover, it is but fair, in an age when trusts and combines, and great corporations get all the blame they deserve, and more, from other people, that those who have profited by them should speak an honest word in their defense.

"I would therefore say that in America, at least, as I presume also in England, the great concerns which install such engines as have been described here are the concerns which employ the best scientific aid, pay the best wages, do the best work, and most effectively serve the human race."

XI

THE APPLICATION OF GAS-POWER IN COAL-MINING AND COKE-MAKING PURSUITS

The remarkable and unprecedented development of economic methods of power generation which has been inaugurated in Germany within the last ten years has benefited the iron industry of that country in a measure superior to that exercised on any other branch of production. It has rendered the relation of power production to power consumption, through the preclusion of additional expenditures for costly boiler coal, more economical, and through the judicious utilization of the available gases and other waste within and outside the works, greatly more profitable.

The simple consideration that a saving of only 1 per cent. in self cost of production may amount to an increase of 10 per cent. and more in net profits secured from the sale of the finished goods has been confirmed time and again in the German iron industry. The economic husbanding of available gases which was discussed in the foregoing chapter, has reduced the price per ton of pig iron smelted by from 50 cents to $1.25, according to the use or salability of the surplus power, and the price per ton of finished goods turned out by from $3 to $4, according to locality. These figures prove better than can any technical argumentation that the economies to be derived from the application of gas power in the iron industry cannot, indeed, be set aside as a negligible quantity.

To point out that the difference in quality of effluent gases from European and American furnaces, which is due to a material difference in temperature of blast, ore analysis, speed of driving etc., is sufficient to warrant any hesitation, on the part of American ironmasters, to follow the example set by the Germans and to utilize these gases directly in gas engines instead of under boilers and in steam engines, means to misunderstand completely the action of the blast furnace as a producer of gas. At the same

time it means to underestimate the efficacy of, or the effect which the cleaning process exercises on, those characteristics of blast-furnace gas that make it an ideal means for directly converting the kinetic coke energy into either blowing work or electrical power.

Even the extraordinarily poor gases which emanate from the furnaces of copper-smelting plants, the calorific value of which does not exceed 400 calories per cubic meter, or 45 B.t.u. per cubic foot, are now utilized for the generation of power, the most notable plant of this kind being that of the Mansfeld Copper Company, of Eisleben, Germany, where the available furnace gases are used in Körting gas engines.

While the paramount importance which these achievements possess in the field of industrial economics is gradually being realized by the metallurgical engineers of all progressive countries, the effect of the application of gas power on the economics of coal-mining pursuits is apparently not yet so well understood and appreciated. It is the object of this study to analyze the possibilities and limitations which confront us when attempting to abandon, in the coal and coke-making industries, the traditional modes of steam-power generation in favor of what is deemed, under certain conditions, the most efficient method of production so far devised, namely, gas-engine-driven central station and electric drive all over the works.

Sources of Power

Conditions differ materially from those which obtain in iron and steel smelting plants, in that the factor of power demand within the plant (coal mine and coke-oven works combined) is much less predominant unless such obstacles as excessive depth of shaft, or abundant water influx, require an abnormal amount of power for hoisting and pumping. Yet even when the power factor is only a small item in the total operating expenses it must be remembered that every cent saved through economic power generation and transmission in the production of one ton of coal will yield tenfold and more in net profits returned from its sale. The judicious selection of the most economical system to be adopted is, undoubtedly, a complexer problem in colliery work, and especially in such as form side branches of existing plants,

than it is elsewhere, on account of the great variety of power sources that are available.

In collieries having coke ovens attached to the mines, which are to transform a certain percentage, usually one-fourth to one-third in European practice, of the annual coal output into coke, there are the following sources of energy which can be used for the generation of power:[1]

WASTE HEAT FROM NON-BY-PRODUCT RETORT COKE OVENS

The burnt coke-oven gases when leaving the flues have a temperature of some 1100 deg. C. (2000 deg. F.) which may be used for steam raising. Assuming that an average of 10 kg. (22 lb.) of steam are required per kilowatt-hour, then 10 kg. of coal(22 lb.) charged into the coke oven will give 1 kilowatt-hour.

It can be taken that, approximately, one-sixth of the value of the coal is thus regained through the sensible heat of the gases which are generated and burnt in this type of oven. The best figure so far recorded is an evaporation of 1.4 kg. (3 lb.) of water per 1 kg. of wet coal charged in the retort. This type of coke oven is now being superseded by ovens of superior construction.

COKE-OVEN GAS FOR USE UNDER BOILERS OR IN GAS ENGINES

When burnt under steam boilers in connection with reciprocating-piston steam engines or turbines, an average of 3 cu. m. (106 cu. ft.) of gas (having a heat value of from 2700 to 5750 calories, 300 to 650 B.t.u. per cubic foot) will be required per kilowatt-hour. When used in gas engines one-third of this amount, namely, 1 cu. m. (35.3 cu. ft.) is consumed per kilowatt-hour. The best result so far attained in Germany is 1 brake horse-power, requiring 2000 calories (7800 B.t.u.), corresponding to 12 cu. ft. of 640 B.t.u. coke-oven gas.

The quantity of surplus gas available per ton of coal, that is, the amount not used for heating the retorts, depends on the grade of coal, on the moisture contents, and on the type of oven. With the non-regeneration by-product type the average is 60 to 70 cu. m. per ton (212 to 247 cu. ft.). On account of the elimi-

[1] The data advanced in the following are based on European and principally on German conditions.

nation of the by-products in the recovery plant the total power developed by the sensible heat of the burnt gases leaving the oven and the inherent heat of the surplus gases is usually less than what is obtained under 1, namely, 0.9 kg. (2 lb.) of water evaporated per kilogram of coal. Of this amount two-thirds is due, approximately, to the sensible heat of burnt gases and one-third to the inherent heat of the surplus gases. It is difficult to define this ratio exactly.

With the latest regenerative type of by-product oven only the inherent heat energy of the surplus gases is utilized, but their quantity is larger, 140 cu. m. (4942 cu. ft.) are recorded in Europe, while with the rich American coals up to 5500 cu. ft. have been attained in United Otto ovens.

WASTE STEAM

Through the application of condensing engines this item has recently been much reduced. Especially engines which do continuous service, such as compressors and fans for mine ventilation, can thereby be operated more economically, while with the hoisting engines and others that operate intermittently the saving in steam is less pronounced.

The recent combination of hoisting engines with Rateau steam accumulators or regenerators and low-pressure or exhaust-steam turbines coupled with electric generators gives additional power without added heat cost, the gain being approximately 1 kilowatt hour from 20 kg. (44 lb.) of waste steam. It is known that steam hoisting engines, with their extremely fluctuating demand for steam, are very wasteful in consumption. The average results show from 50 to 60 kg. (110 to 132 lb.) of steam per shaft horsepower per hour and more. But as low as 29 kg. (64 lb.) have been recorded on German mines, the engines being of modern type and working with an improved admission-governing device.

It has also been found that for hoisting engines, working with full admission and short expansion, condensing does not pay, whereas with engines having an ample range of expansion the connection with a central condensing plant is an advantage. The addition of waste-steam turbines and Rateau accumulators will increase the economic efficiency of the first-named type of engines more than it will the latter. In some cases the increased capital outlay will annul the gain in steam economy entirely.

The question is again strictly one of local conditions. By far the best plan for a new steam plant to be erected would obviously be to eliminate central condensation entirely and to install low-pressure steam turbines instead. This is a feasible proposition, provided that the turbines can fully utilize the available steam, and that there is a field for the surplus energy thus gained either within the colliery or outside. We shall enlarge upon this subject further on.

INFERIOR GRADES OF COAL AND MINE CULM

The relatively better grades can either be burnt under boilers for steam raising or be directly gasified in producers. The generation of steam power requires, with coal-fired boilers, in the neighborhood of 1.5 kg. (3.3 lb.) of coal of 6000 calories per kilogram (10,800 B.t.u. per pound) per kilowatt per hour. With gas-fired boilers, the gas being made in producers, the same amount and sometimes less is used, depending on the character of the particular coal used.

The generation of gas power in gas producers and gas engines requires only 0.75 kg. (1.6 lb.) per kilowatt per hour, and usually less.

Mine culm is now in almost all collieries stored in huge piles, which occupy an enormous space. With limited floor area, as obtains, for example, in narrow valleys or creeks, it is necessary that the culm be removed from time to time. Under especially unfavorable territorial conditions this may require the building of tunnels, railways, etc. Therefore, it is obviously a great improvement to dispose of culm banks by direct gasification of the material in producers, gaining, beside an enormous amount of surplus power at no added heat cost, a welcome reduction in weight and volume of waste that has to be handled, thereby reducing the item of labor which must be expended for that purpose correspondingly. In Germany several collieries are equipped with culm producers, which usually serve as an auxiliary or reserve to other sources of gas generation. (See Chap. XII.)

ELECTRIC CURRENT

Collieries having no coke-oven plant connected with the mines may use, for producing motive power, electric current from

neighboring or distant central stations. This most modern, convenient, and economical form of application eliminates the special power house with its prime movers, generator equipment, and reserves, each mine having but a transformer substation, from which the various motors for hoisting, pumping, ventilation, etc., are driven.

Old established mines have, of course, all their individual power plants, most of them being laid out as steam-driven electric stations with scattered steam drive of the larger machines. So, electric distribution is only possible when branching out or when opening up new coal fields. Usually the mine which has the best coal for coking purposes will have a central station equipped with gas-engine-driven alternators, the potential of which is to depend on the dimensions of the coal fields or on the radius of the particular distribution sphere available. The other shafts or places of usage receive their required electric current, according to their respective momentary demands, without having to pay the capital and depreciation charges for special power plants, at the same time having the guarantee of continuous supply and ample reserve.

For equalizing load fluctuations such as occur especially in hoisting service, Siemens-Ilgner fly-wheel sets, which employ the inertia, or, better, the power-accumulating capacity of very heavy fly-wheels, have given great satisfaction in German practice.

OTHER FUELS

When coal tar oil or its derivatives are available at low cost a very economical source of power generation is offered by the direct combustion of these fuels in Diesel oil engines.

The use, in colliery work, of oil and natural gas may seem paradoxical at first sight. But the question is entirely one of local conditions and load factor. The possibility offered by the application of gas or oil power, of immediate starting, the absence of steam boilers, and pipings with their condensation losses, the reduction and practical elimination of stand-by losses, and other factors besides, are to be considered.

No general formula can be laid down, and each problem must be treated separately. Soundness of judgment is the only rule to guide one. Compressed gas and oil fuels may be used either

for driving the prime movers in the central station, and having pure electric drive all over the works, or for operating the scattered engines at their respective places of usage. The greater possibility of breakdown, the higher class of attendance required, and the inability to carry heavy overloads, are some of the drawbacks militating against the latter application and favoring centralization.

Altogether, the combinations designated under 6 are more of a speculative than of a practical nature. Yet they may occur and should therefore be considered in a discussion of this character.

Uses of Power

AMOUNT OF POWER AVAILABLE

Just how much of the power derived from one or more of the above-named sources of energy will be consumed within the plant is entirely a matter of local conditions. None of the data advanced on this subject can be generalized. At best they may serve to give an approximation to the truth. The amount of surplus power available for outside purposes depends on the moisture and quality of the coal coked, and the quantity of the coke output, on the type of oven and on the demand for power for operating the machinery within the works.

As an average example of German practice can be taken a colliery in the Ruhr district having an annual coal output of 600,000 tons, of which one-fourth is coked. From waste heat and waste gases a continuous capacity of 3000 h.p. is obtained, of which as much as 2500 h.p., or 83 per cent., and sometimes more, are consumed within the works.

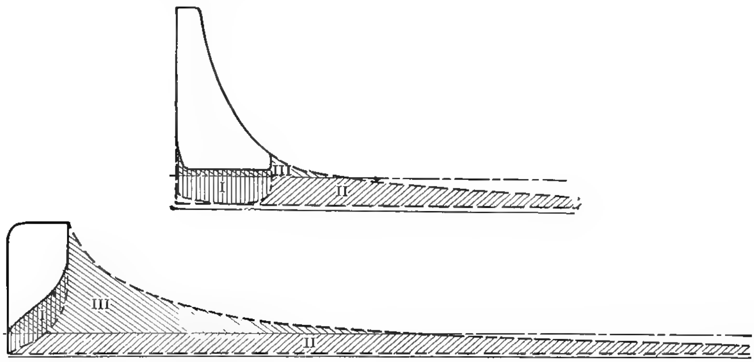
The growing introduction of the regenerative type of Otto by-product ovens tends to increase the amount of surplus power available for outside distribution or sale. The largest German colliery, "Rheinpreussen," will shortly have an annual output of 3,000,000 tons, of which one-third is coked. A very conservative estimate shows that 17,000 h.p. can be generated continuously from the coke-oven gases in gas engines. Owing to the small depth of shafts and little water influx, only 58 per cent., namely, 10,000 h.p., will be consumed within the works, the rest being available for outside uses.

The item of surplus power is, with the rich American coals, when coked in the latest type of United Otto by-product oven,

even much greater, and gas power seems therefore the only legitimate mode of generation prescribed.

LOW-PRESSURE OR EXHAUST-STEAM TURBINES

In order to be able to discuss intelligently the prospects of gas-power application in colliery work, it is necessary to get quite clear as to the possibilities and limitations which confront us in the application of central or direct steam drive, especially since the low efficiency of old-fashioned engines has been greatly im-



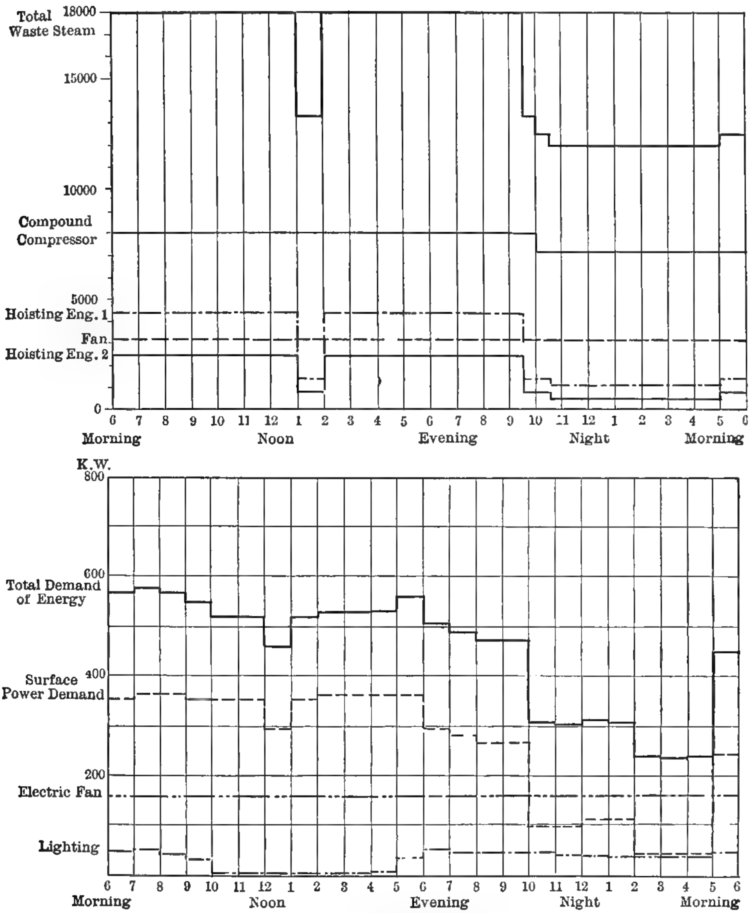
FIGS. 147, 148. — Diagrams Showing Economies to be Derived from the Application of Exhaust Turbines with Good and with Bad Engines, Respectively.

proved by the introduction as well of modern condensing steam engines as of the low-pressure exhaust or waste-steam turbines.

Dr. Hoffman, of Bochum, in commenting on this new system in a paper read before the Verein Deutscher Ingenieure at Berlin, gives the following figures on the performances of compound engines versus such exhausting into low-pressure turbines: With 1.2 atmospheres (17.6 lb. per square inch) admission pressure and 90 per cent. vacuum, low-pressure cylinders of several hundred horse-power capacity consume approximately 24 kg. (53 lb.) of steam per kilowatt-hour. Low-pressure turbines of over 1000 h.p. capacity, on the other hand, working under the same conditions, give a guaranteed consumption of 18 kg. (40 lb.) of steam per kilowatt-hour. Not included are losses due to condensation in the pipings.

Up to the middle of 1906 ten plants of the low-pressure turbine type, aggregating an output of 8000 h.p., had been installed in German collieries. The accompanying Figs. 147 and 148 show the

improvements that may be effected from the application of low-pressure turbines, with good and with bad engines respectively. Area *I* represents the gain that can be made by condensing, area *II* is the surplus gain effected through the turbines, and



FIGS. 149, 150. — Diagrams Showing Relation of Power Available and of Power Required in Different Departments of Large Mine.

area *III* represents the loss which is unavoidable, notwithstanding the new improvement.

It is seen that low-pressure steam turbines can improve considerably on the low efficiency of bad engines, but they can never make good engines out of them. Figs. 149 and 150 show the

relation of waste steam available to electric energy required in the Alma mine, which is a branch of the Gelsenkirchener Bergwerks Gesellschaft, having an annual coal output of 600,000 tons.

Since the exclusive adoption of gas power, which means having coke-oven gas engines in the central station, gas producers as a reserve, and employing electric drive for all machinery throughout the plant, eliminates the use of steam boilers almost entirely, the above reference to the position which the low-pressure and waste-steam turbines occupy at this date in the steam-power problem of collieries will be all that is necessary to say on the subject.

DISTRIBUTION OF POWER WITHIN THE PLANT

Before discussing the merits of electric centralization and pointing out the relative advantages and drawbacks of the three principal types of prime movers, piston steam engines, turbines, and gas engines, which may be employed in the power house of a combined coal mine and coke-oven plant, it may be well to analyze the distribution of uses to which the power derived from the various sources can most advantageously be put within the domain of the works.

Since it has been recognized that a judicious administration must aim toward the utilization of all available waste or low-grade fuel that is produced within the plant before having recourse to costly boiler coal for generating power, the most natural way, in works that coke a sufficient quantity of rich coal, is undoubtedly to use the available coke-oven gases either under boilers or directly in gas engines. The power thus liberated should preferably be consumed at once in the different departments of application: hoisting, pumping, compressing, washing, etc., in the same measure as it is produced.

Since the production of gas in the coke ovens and therefore the generation of power is a continuous process, a combination of this character would only be feasible if we had an ideal plant-load factor, namely, if the utilization coefficient was 1. Unfortunately this is not the case, as can readily be seen from Fig. 150. Few of the engines are in continuous operation during the 24 hours of a daily run, or during the 32 or 36 hours which constitute the coking period of modern ovens. Among these are the prime movers in the electric central station and the fans for

mine ventilation. Sometimes, depending on local conditions, drainage pumps and compressors must also do continuous service.

So it is natural that one will try to connect these continuous users to the continuous sources of power, namely, to the coke-oven gas driven part of the power plant, while such intermittently working machinery as the large hoisting engines will be connected to the other part of the power station, which derives the dynamic medium from either gas producers and engines, or gas-fired boilers and engines.

Though it is possible to store surplus coke-oven gas during periods of low demand in holders, or to accumulate it in form of electrical energy in storage batteries, it is obvious that these provisions mean an increased capital outlay and fixed charges for additional apparatus and ground area, an item which is considerable when the storage capacity shall be large enough to be of real value as a reserve; when employing producers which are fired with culm or other waste or even coal-fired boilers, then the consumption of power and the expenditures for fuel can be more nearly balanced.

The modern coke oven, owing to its capability of subdivision and reliability, is an ideal apparatus or source for the continuous generation of gas, and needs practically no reserves in contradistinction to the blast furnace, when either a coefficient of safety must be introduced in the disposal of the gas, or else a bank of gas producers should be available as a reserve, unless the plant has at least three or four furnaces. This leads us to the discussion of another question of vital interest, namely:

GAS PRODUCER VERSUS STEAM BOILER

The effect or importance which the load factor and the initial cost of equipment possess in the columns of steam power-plant economics is generally known. It is now also a matter of universal concession that gas producers and engines are greatly more adapted for intermittent working than are steam boilers and engines. The amount of fuel required to keep the gas producer in such a state that it can be put into full work at a few minutes' notice is a mere fraction of the amount required to keep steam boilers with their fires banked.

Where sudden increases in load may occur at any time and

full steam pressure must be kept up, the stand-by fuel losses amount, even in the best regulated boiler plants, to 30 per cent. and more of the full load-running fuel, while certain types of producers will stand with air-admission doors almost closed, for one and more days in a condition of preparedness for instant operation, requiring but a few buckets of coal to replenish the fuel bed, and a motor-driven fan which will quicken the fire to full heat within a few minutes after giving the starting signal. They only require about one twentieth part of the fuel that is necessary in steam boilers for banking fires over night or during periods of light load. In one case cited by Mr. Dowson the stand by losses on a 500-h.p. steam plant have been assessed as 15 per cent. of the total fuel consumed in 24 hours, while the stand by losses in a gas plant of equal capacity only amounted to 2 per cent. of the total coal consumed.

For this reason producers are admirably adapted to serve either as the principal source of gas generation or as a reserve; for example, in blast-furnace work and in the natural-gas region. Their economy of operation is due notably to the fact that such low grades of coal as "culm" and others with high ash contents may be used as fuel, which cannot at all be utilized under boilers; further to the fact that they serve as a central means for producing heat, light and power; also to the peculiarity mentioned, that they will retain their high efficiency on low outputs; and finally, to their ample overload capacity combined with the desirable feature that, when properly subdivided into separate units or retorts, and embodying means separate from the engine to automatically vary their output according to the momentary demand, they will stand all the strain exercised upon them by a very fluctuating plant load.

All these advantages of superior economy and simpler operation are now so well known that together with the low initial cost and up-keep, absence of danger from explosion, elimination of smoke nuisance, etc., they are bound to impress themselves favorably on the mind and purse of the intelligent user of power. The ultimate adoption of the suction type of producer has also eliminated the bulky, inefficient, and costly gas holder, at the same time obviating the use of special coal-fired boilers for producing the steam that is required in the gas-generating process, and which is now gained from the waste heat of the producer gas.

The employment of electrically driven fans, which are automatically regulated from the central station according to the load, for doing the suction work instead of steam ejectors, has made the engine practically independent of the gasification process, and has increased its capacity in a ratio corresponding to the difference of admission pressures of the dynamic media at the intake.

Electric Centralization

In the majority of cases the power system in combined coal mines and coke-oven plants consists of a central boiler plant which supplies steam to a small electric lighting and power station and to the various large and small engines which are scattered over the plant and serve to drive the respective winding, pumping, compressing, etc., machinery directly. We shall refer to this form of application as direct steam drive. When gas power became a claimant for recognition in this field, and when it was found desirable to generate all the required power from the available gas or waste without added heat cost, the conversion of energy in gas prime movers and the distribution of these engines along the different places of usage seemed the more desirable.

Provided that modern regenerative by-product ovens constitute the coking plant, this system of direct gas drive has even now many points to commend it. In the meantime, however, the situation has assumed a greatly different aspect since, through the rapid development of the electrical industry, and that of the steam turbine and large gas engine, the generation and transmission of electric current, at least within moderate ranges, has become so reliable and economical that we are getting more and more inclined to adopt either one of the two methods: steam-turbine-driven central station or gas-engine-driven central station and electric drive all over the works.

I propose first to comment on the advantages which are to be derived by central electric drive irrespective of whether gas or steam prime movers are used in the power house, and compare them with what obtains with either direct gas or direct steam drive.

It is an undeniable fact, established in numerous cases of actual practice, that electric centralization enables a colliery, when working under normal conditions, to cover all outside

power demands from the available coke-oven gases even when steam drive is adopted in the central station. Therefore, when laying out the power scheme for a new mine, regardless what be the character of the mineral or metallic ores to be produced, it is wise to give to the central electric drive the first consideration, also to reserve in the general layout provisions for future expansion and for the distribution of surplus power to neighboring districts and for the operation of electric railways throughout the commercial-distribution sphere of the works, which application might be projected later on.

SYSTEMS OF POWER TRANSMISSION COMPARED

Obviously, the most economical method of power generation in the central plant will be of no value unless the planning of the transmission and distribution system and of the mode of application is done with proper care and with observing, in the layout, definite and predetermined principles, since otherwise the losses occurring in the application will annul the savings realized in the production. There are to-day five different systems of power transmission in vogue in combined iron-smelting plants and coal mines: Steam, compressed air, hydraulic, gas, and electric transmission. They all have one feature in common, namely, that the area of cross section of the transmission line bears a definite economic relation to the pressure of transmission of the dynamic medium.

With steam it is the loss through condensation in the pipe lines that demands a smaller pipe cross section, which in turn necessitates the adoption of higher steam pressures. With compressed-air transmission, also, heat losses must be compensated for by a reduction of the radiating surface, namely, smaller diameter of pipes, which can be had only at the expense of higher air pressures. The larger the pipe cross section of hydraulic mains, the greater the danger of freezing, and the greater the difficulty to guard against leakage. With gas, conditions are much more favorable, because condensation losses are entirely absent, and the higher the calorific value or heat density of the available gas, the better will be the all-round economy of the system. Yet it would not pay at all to transmit the weak power gases, such as blast-furnace gas, beyond the immediate proximity of the blast-furnace plant.

The above-mentioned losses through leakage and condensation are entirely absent in the electric-transmission system, so that the efficiency of long-distance transmission is relatively high, from 95 to 98 per cent., provided that the voltage has been correctly proportioned to the respective distance. The losses which do occur in the electric-transmission system are pure tension losses, being dependent on total length, cross section, and capacity of the conductor; but there are none due to changes in the form of energy. Of course insulation must be perfect, and here is where the main difficulty lies, as we shall see later on.

DIRECT VERSUS ALTERNATING CURRENT

The economy of electric transmission depends on the proper selection of the mode of current and of its voltage. But since the determination of these factors does not to any great extent affect the economy of power generation proper, with which we are here chiefly concerned, it will suffice to say just a few explanatory words on this subject.

Speaking first of combined iron-smelting plants and coal mines, which combinations grow rapidly in number and extent owing to the general modern tendency to combine in order to be able to work with maximum industrial economy, direct current between 440 and 550 volts will be applicable for all purposes in or near the blast furnace, coke oven, and power plant, also in rolling mills, if closely located. For transmission over large distances, direct current is also preferred, so long as the places of usage fall within the commercial-distribution center (some 600 volts tension). Beyond that alternating (three-phase) current of 5000 volts and more must be chosen. F. Janssen, Berlin, in discussing this question, gives the following comparison of the respective advantages and disadvantages of direct current versus alternating current.

DIRECT CURRENT

Central Station. — Possibility of equalizing load fluctuations to a large extent; "puffers," storage batteries or other means for the accumulation of energy, therefore favorable conditions for efficient fuel conversion and utilization in the prime movers.

Transmission. — Tension limited to 600 or 700 volts as a

maximum, therefore distribution of electric energy over wide distances uneconomical or impossible.

Substation. — Motors susceptible of control, with economical means of starting, braking, and speed regulation; simplest conduction of current.

ALTERNATING CURRENT

Central Station. — Bad load equalization, inefficient utilization of the dynamo; therefore "puffer" or accumulator stations between generators and motors are necessary.

Transmission. — High tension is possible; therefore also the distribution of electric energy over any distance practical and economical.

Substation. — Motors are simple and can be connected directly to the high-tension net. They are best suited for working in one direction of rotation and at constant speed. (Ideal transmission motors.) They are less fit for reversible and such drives that must be capable of control (steel works, rolling mills), and for transportation purposes. Transformers and converters are necessary.

From the above it is seen that the realm of application of direct current is limited to blast-furnace plants, steel works, rolling mills, coke ovens, and auxiliary drives. Moreover, it is necessary that the central station is located near the principal place of usage. Alternating current is best suited for such central stations as are to transmit the energy of waste gases over wide distances, for instance to neighboring blast-furnace plants and coal mines; also for parallel operation of distant central stations; further, for the distribution from some central plant of electric current to several industrial establishments (overland centrals), and for the transmission of energy over wide distances (electric railways).

A combination of both systems by the interposition of alternating-current direct-current converters as intermediary members will obviously be suited to all conditions, the higher initial cost being counterbalanced by a number of other advantages.

CENTRAL VERSUS SCATTERED DRIVE

Now, as to the superiority of electric centralization over scattered gas or steam drive the following gives a brief résumé

of the principal points: The main conductors from the central station to the various departments can be laid as underground ring cables, thus giving hardly any cause to interruptions in the supply service. Pipe lines for gas and principally for steam must be carried overground and be easily accessible on account of the repairs which occur frequently. Their initial cost is also higher. Direct steam drive causes enormous condensation losses in the pipe lines, which continue even when the engines are not running and which preclude the employment of high steam pressures, which otherwise would be adopted for securing higher economy.

With scattered gas engines there are, it was said, no condensation losses in the supply pipes. But there is this drawback, that each set requires separate provisions for back-cooling the jacket water, which are both costly and complex. The securing of skilled attendance at reasonable cost, which is yet a factor of some weight for the successful operation of gas engines, especially in this country, is a problem that is multiplied the greater the number of independent installations, while in the central station it is a single factor that can very well be taken care of.

The same line of thought applies to the matters of floor space, foundation, complication, necessity of reserves, etc., which are less favorable for gas engines than for steam turbines. Therefore the future and the success of gas engines for large-scale production lie with large units operating in the central station, where all its weaknesses can be equalized and minimized. Provisions for ample reserves and spare units, for high-class attendance, perfect control, and a favorable distribution of the plant's loads can best be made in one central power house.

DIFFICULTIES OF ELECTRIC DRIVE

The generation of high-tension electric current is just as simple and reliable a matter as is that of current of lower potential. The only real difficulty which still exists lies in the transmission system. The interdependence of the different sections of one net and their liability to break down owing to insulation troubles, short-circuiting, sparking, overloading, etc., are its weakest points.

While there are automatic provisions to protect every individual generator against overloading, there are none as far as

the effects of surges on the line are concerned. Altogether, our understanding of the phenomena occurring in a high-tension transmission net are still very limited and the possibilities to amplify our knowledge by proper experimentation are almost nil. But, as was said, this is perhaps the only point which is capable of improving. Generators, transformers, and electric motors, it is conceded, are simple, compact, self-contained, and reliable machines. Their operation and up-keep does not require extraordinary expenditures. Their floor space is small and therefore the housing for each separate drive is cheaper than it would be with either gas or steam engine. Their initial cost and the cost of foundation required is also less.

ADAPTABILITY TO FLUCTUATING LOAD

Another principal point: Electric motors adapt themselves much more easily to fluctuating-load conditions and the whole system loses its rigidity of operation, becomes widely elastic, better regulated and more easily controllable from the central plant. It is much easier to throw in a new motor when so desired, and the provision for reserves or spare units at the different places of usage is decidedly cheaper.

Further, there is this great advantage about electric drive: that the great variety of types and models, which is a feature of necessity of direct drive, can be dispensed with in favor of a few standard forms and sizes. For the efficiency of electromotors decreases only very slightly with the lowering load in contradistinction to that obtained with gas and steam engines. If a small electric motor breaks down, a reserve motor can be installed immediately. Not so with gas and steam engines. Extremely heavy overloads, which occur quite frequently in colliery work, can be fully met by electric motors, which are susceptible of momentary overloads of 100 per cent. and more without suffering harm. They may therefore be selected of a medium capacity and will yet suffice for the maximum demands.

One of the greatest and well-known drawbacks of the gas engine is, beside that its range of economical load is limited to between 50 per cent. and the maximum, that it cannot be overloaded. When underrated by the manufacturer, a nominal overload capacity of 15 per cent. is all that may be reasonably expected.

As already mentioned, the possibility offered by electric centralization to so distribute the various phases of a daily load that a more even curve results enables one to protect the gas engines in the central station against undue maxima and minima.

With scattered drive the capacity of (gas) engines must be made to correspond to the maximum load which may eventually occur. Therefore they will work normally with lower efficiency and higher fuel consumption than could be attained under more favorable load conditions. Besides all this it is a very desirable feature with central electric drive that the consumption of power and its fluctuating demand can be readily observed and registered at the switchboard in the central station, while with direct gas drive this is more difficult and with direct steam drive it is practically impossible. This continuous control means a saving of thousands of dollars per year in plant fuel cost.

MACHINES LOCATED NEAR THE BOILER PLANT

It was held until a short while ago, and by some is held even now, that electric drive of those machines which are located in the near vicinity of the boiler plant, and especially those that work continuously, like compressors, fans, etc., would bring no advantages through a reduction of plant fuel consumption. That this idea is erroneous so far as steam drive is concerned will be appreciated when making the following consideration: Large and continuously operating steam engines of from 100 to 500 h.p. capacity are normally built as compound engines having a steam consumption of about 8.5 kg. (18.7 lb.) per effective horse-power per hour. By combining, through centralization, all their power in the central station, we get units of 1500 h.p. and more, which are normally built for a steam consumption of 5.6 kg. (12.3 lb.) per effective horse-power per hour.

Assuming for the conversion of the mechanical power into electric energy, and for transmission of the current to the place of usage, and for its transformation there into motion, a liberal loss of 20 per cent., then the item of steam consumption in the power house increases in a ratio of 5.6 to 0.8, that is to 7 kg. (15.4 lb.), so that even then 1.5 kg. or 3.3 lb. of steam are saved per horse-power per hour through the employment of large prime movers.

A similar line of thought shows that the small electric motors are equally benefited, since the current for them is produced cheaper than in smaller generators, such as are used nowadays for delivering current to the smaller motors. It should be considered that the great condensation losses in the pipe lines and engines during idle periods or with low load factor are not included in the consumption figure of 18 lb. given above, and that all these losses are absent in central electric drive.

Various Services

PUMPING SERVICE

Constituting as it does the most important item of power consumption in colliery work, we shall have to devote a few remarks to the development which led to electric centralization in this particular department. Formerly the subterranean steam pumping plants used to occupy the predominant and undisputed place. Their efficiency depends greatly on whether the service rendered is intermittent or continuous, since there is obviously a great loss due to condensation in the pipes descending down the shaft, such loss lasting all the time, regardless whether or not the pumps are operating. Under very favorable conditions of operations such as obtain, for example, in the 1500-h.p. plant in the Victor mine, Germany, on which a test is available, as high efficiencies as 89 per cent. may be attained, the total loss in steam consumption not exceeding 10 per cent. The largest steam plant of this type ever built in Europe is working with triple expansion, and is supposed to lift 25 cu. m. (883 cu. ft.) of water against a head of 500 m. (1640 ft.), corresponding to a power capacity of 3000 horse-power.

Later on, the hydraulic system of raising water, of which we have in Germany 46 installations with a combined capacity of 165 cu. m. per minute (5825 cu. ft.), took the place of the steam drive, to be superseded finally by the electrically driven pump. The advantages embodied in this latest application are so obvious that there were, according to Dr. Hoffmann's report at the beginning of 1906, in the Ruhrkohlen district alone, 110 installations aggregating a prime-mover capacity of 50,000 horse-power.

It was a natural consequence of the introduction of electric drive that the design and construction of pumps would thereby

be modified to a certain extent, especially that the profitableness of higher speeds would be considered. And so we find now, with piston pumps, an average working speed of 100 and even 120 r.p.m. against the 60 revolutions of earlier years. This, which we may call a transient type, is known also in this country under the name "Riedler Express Pump," and has served as a model to many builders. The largest electrically driven pumping plant of this kind, and I think the largest altogether, is the one operating on the Colonia mine, near Langendeer, which lifts 20 cu. m. per minute against a head of 435 m. (703 cu. ft. 1427 ft. high).

Centrifugal Pumps.—The desirability of even higher speeds led to the adoption of centrifugal pumps, which are cheaper in first cost, attendance, and floor space, and though considerably inferior in efficiency have conquered within very little time a remarkable percentage of the total service. As a matter of fact, by far the greatest quantity of water in continental mines is lifted by centrifugal pumps.

It was said that it had been conceded for a number of years that electric drive is handy and economical for medium-size and small engines which are located at a good distance from the boiler plant, and that the saving in fuel cost, attendance, lubrication, and waste, also the low initial cost and other advantages referred to, warranted the installation of electric motors at those specific places. It has now also been evidenced that the draining and pumping of water in mine work can be done with greater all-round satisfaction by the adoption of high-speed centrifugal pumps, which are driven by air- or water-cooled inclosed electric motors of the three-phase current type, and which receive their energy and are controlled usually from transformers located at the mouth of the pit, with greater all-round efficiency, reliability, and economy of operation.

The pumps are usually of the twin-series and triple-series types, running at from 800 to 1000 r.p.m., and are mounted with the motor on a common base plate carried on trolley wheels, so that they may be used in any part of the mine. In the lead and silver mines of Ems, Germany, a pump of this type is lifting 9000 cu. ft. of water per minute against a head of 800 ft. Also for washing work in collieries these electrically driven pumps are now largely employed. Among the latest installations must be mentioned one built by Emil Sinell, of Berlin, for the Donners-

marck mines in Upper Silesia. The high pressure centrifugal pump lifts a quantity of 10 cu. m. (353 cu. ft.) of water against a head of 315 m. (1040 ft.), being driven by 950 h.p. three-phase current motor of the Brown, Boveri & Co.'s type.

Another remarkable installation of this kind which was recently tested as to its all-round efficiency is operating in the Victor mine, near Rauxel, Germany. It lifts a quantity of 7 cu. m. per minute against a head of 500 m. (247 cu. ft. 1640 ft.) at 1000 r.p.m. The capacity of the prime mover which serves to generate the necessary electric current is 1400 h.p. indicated. The total plant efficiency is 59 per cent.

In commenting on relative efficiencies of steam, hydraulic, and electric pumps it must be considered that the issue of a comparison is largely dependent on the respective favorable or unfavorable conditions under which the different systems, especially electrically driven centrifugal pumps, are operating. Conditions are poor for the latter type when the quantity of water is small and the head high.

Also, the results are greatly influenced by the manner in which the centrifugal pumps are driven, whether they receive their current from the network of a central station, or whether they possess their own separate generators driven by either gas or steam engines or turbines. The advantage of the last-named combination with centrifugal pumps consists, first, in that the number of revolutions of the pumps is kept constant without additional water-throttling regulation, since the prime mover will keep its speed automatically with fixed governor. While, when the pump is taking its energy from a network of unchangeable frequency, a special throttling device for the water must be provided in order to prevent interruptions in the flow, such throttling being apt to decrease the efficiency of the pumping process more or less.

Another advantage of employing a separate engine- or turbine-driven alternating-current generator lies in the possibility thus rendered to distribute the pumping work, which represents the largest single factor in the plant's load, over such periods during which other (hoisting) engines are not running, for example, over night, thereby keeping the consumption of power proportionate to the production of gas, that is, nearly constant.

Figure 151 gives an approximate idea of the relative efficiencies of a steam, a hydraulic, and an electric pumping plant for mining

work, and also shows the distribution of losses which occur in electric centralization. The test was made in the Franzeska mine in Witten, by the Verein Deutscher Ingenieure, and represents results such as are obtained under actual working conditions. The term "efficiency" applied to electric pumping means the ratio of water lifted to work indicated in the (steam) engine. In the particular case under discussion the latter serves to drive an electric alternating-current generator, which in turn delivers

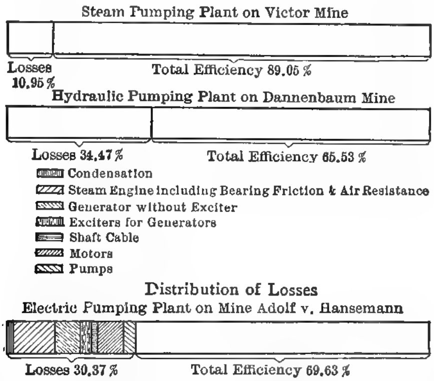


FIG. 151. — Diagram Showing Relative Efficiencies of Steam, Hydraulic and Electric Pumping Plants in German Coal Mines.

three-phase current to the subterranean motor-driven pumping equipment (piston pumps at 80 revolutions per minute).

It is seen that, notwithstanding the many losses occurring between prime mover and pumps as indicated in the diagram, the total efficiency of the electrical pumping equipment runs almost as high as 70 per cent. Since the long-distance distribution of high-tension electric current has been through the economic generation of electricity in gas-engine-driven central stations operating on coke-oven gas, etc., so widely adopted all through the industrial districts in Germany, it is to be expected that complete centralization, that is, centrifugal pumps driven by electric motors which derive their current directly from the line, will be the predominant mode of operation before long.

HOISTING SERVICE

One department which seemed hitherto almost exclusively reserved to direct (steam) drive is that concerned with taking

the mine workers up and down the pit, also with lifting the broken ore or rock or coal to the surface, to be there screened and washed, and finally charged into the (blast) furnace or coke ovens, or to be shipped directly to the consumers. Since hoisting service presents perhaps the most fluctuating of factors which constitute the load curve of a colliery, and since we can only arrive at just conclusions regarding the prospects and limitations of gas power as a claimant for recognition in this class of work by understanding the manner of operation of every important branch of application, and its back effect on the prime movers in the central station, it will be necessary to devote a few explanatory words to the operation of hoisting engines.

Steam hoisting engines are very simple, safe, and reliable machines, and quite excellent but for the one disadvantage that they are extremely uneconomical owing to the severe and fluctuating demands of the hoisting load. By far the majority of engines tested show an average steam consumption of between 50 and 60 kg. (120 to 132 lb.), some obsolete types as high as 100 kg. (220 lb.), other high-class engines only 29 kg. (64 lb.) per shaft (pit) horse-power-hour.

This high economy is chiefly due to the improved type of engines, to the employment of high steam pressures and superheating, to the avoidance of harmful clearance spaces by placing the valves on top and bottom ends of cylinders, to improvements in admission-governing devices, and last but not least to the greater depth of the pit which allows the engine to develop its capabilities and to utilize the advantages of compounding and prolonged expansion.

Electrically Driven Hoists. — The economy of operation of electrically driven hoisting (winding) engines for main-shaft winding service depends chiefly on the mode of current adopted. On account of the many advantages which three-phase current possesses over other systems for operation in mines, it would be most desirable to use it also for driving hoisting engines. However, the speed regulation of alternating-current motors in hoisting service is difficult, depending as it does on so many varying influences. Also it is hard to protect these motors sufficiently against excessive load fluctuations. The use of fly-wheels equalizers is not satisfactory, while storage batteries with motor generators, though effective, are too expensive in first cost.

Further, it is very difficult to build three-phase current motors of 100 h.p. for a frequency of 50 periods for a speed of between 40 and 50 r.p.m., while this is possible with direct-current motors, which may therefore be directly coupled to the shaft of the hoisting drum.

Finally, on account of the peculiarities of hoisting service, the consumption of energy in three-phase current motors depends greatly on the skill of the attendant and is usually higher than that of direct-current motors. Therefore the latter type of motors, especially when connected with the Leonard system of regulation, — hoisting motor driven by direct-current generator, — is coming into almost universal use in Germany.

Leonard System of Regulation.—It would go beyond the scope of this study were we to discuss in detail the advantages which this mode of driving embodies over three-phase current work. They may be briefly summarized as follows:

The hoisting speed is independent of the load and can be chosen higher than with either direct steam drive or three-phase current motors. Therefore the rate of output from the pit is increased. The speed of driving is only dependent on the position of the starting lever and the arrangement can be made absolutely safe and controllable.

The consumption of power is not dependent on the skill of the attendant and can therefore be guaranteed beforehand. Diagram Fig. 152, which was presented by Phillipi in a paper read to the Verein Deutscher Ingenieure, shows the relation of the current consumed by the hoisting motor (1) to the varying potential of the armature of the motor (2), the product of both representing the amount of energy consumed by the hoisting motor.

Another great advantage of the Leonard system of regulation is that it offers convenient and perfect means for equalizing load fluctuations. Leaving out of consideration the case that the regulating direct-current dynamo is driven directly by some steam or gas prime mover, though this is often the most economical mode to pursue, we shall here consider what obtains in the majority of cases in modern European practice, namely, that the dynamo is driven by a special motor which works at a constant potential, taking its current from the network of some central station.

Alternating-current Direct-current Transformers.—The advan-

tage of having a converter set for transforming the three-phase current delivered by the line into direct current, which is employed for driving the hoisting motor and drum, consists chiefly in that the arrangement allows connecting even the largest main-pit winding engine to any net without disturbing other consumers. It is therefore no longer necessary to provide a power house for every mine, so long as electric current from some reliable source is available.

Ilgner Fly-wheel System. — The great improvement which Ilgner has introduced in the operation of these alternating-current direct-current converter and hoisting sets consists in that he placed a very heavy fly-wheel, having a weight of from 30 to 40 tons for large work, on the shaft of the motor generator, which

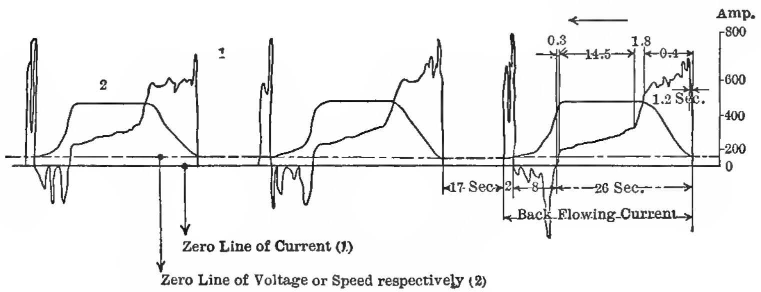


FIG. 152. — Distribution of Current Consumed by Electric Hoisting Motors (Leonard System).

absorbs all shocks and fluctuations that are exercised through the direct-current hoisting motor on the direct-current generator, thereby preventing any back effect on the net, which would be harmful to the generators and prime movers in the central station. At the same time the fly-wheel acts as an accumulator storing the energy which is furnished from the net at a continuous rate also during the hoisting intervals, and giving it out again during the starting period of the hoisting motor.

The direct-current drive of hoisting engines combined with the Ilgner puffer system has rendered hoisting service a constant and beneficial contributor to the station load, and the addition of a special safety device, which we cannot here describe, has made the equipment so controllable and reliable that the hoisting speed in German mines was, by sanction of the mining authorities, increased from 6 to 10 m. per second.

Economy of Electric Hoisting Service.—Regarding the economy of central electric drive, the opinions of mechanical and electrical engineers are still diverging. Some hold that the economy of high hoisting speed and the safety of operation are too dearly bought by the higher initial cost of equipment and the higher losses in transmission and operation, especially through bearing friction of the heavy fly-wheel. Others maintain that, considering all the items which contribute to the total cost of equipment, that is, not only the portion represented in the hoisting plant, but also the corresponding portion of the power plant proper, the comparison comes out in favor of straight centralization.

This refers as well to direct drive by three-phase current hoisting motors, which take their energy directly from the line, as to the direct driving of the regulating dynamo by special prime mover. Of the combination employing three-phase current motors operating from the net without transformers, we have in Germany only few examples, the best known being that on the "Preussen" mine, which lifts a load of 2200 kg. 700 m. high (4840 lb. 2296 ft.) at a speed of 16 m. (52.5 ft.) per second. It is even maintained that straight centralization is cheaper in total cost than ordinary steam drive, and it is true that in the last-named case such items as larger boiler plant, steam piping, more spacious building for hoisting engine, and the far greater consumption of coal, oil, and waste must carry considerable weight. A steam consumption of 10 kg. (22 lb.) per shaft horse-power, as recorded with central electric drive, is twice as good as the best result that has so far been obtained with modern high-class direct steam drive under exceptionally favorable conditions of operation.

Operating Expenses. — As regards operating expenses with central electric hoisting service the consumption of power will very largely depend on the losses which occur between prime-mover shafts in the power house and hoisting drum. While for large steam engines operating in the central station as low as 5.2 kg. (11.4 lb.) of steam per effective horse-power-hour has been attained, the corresponding consumption in the pit was found to range from 14 to 11 kg. (30.8 ÷ 24.2 lb.), giving for a continuous day and night run of 24 hours a total efficiency ranging from 37.5 to 44 per cent., according to the time at which records were taken. Ilgner gives the efficiency between drum shaft at pit

and bus bars in the central station as 55 per cent. for large, and as 45 per cent. for small hoisting plants, which are operated directly from the network of a central station.

That this system has its indisputable merits is best proved by the rapid introduction which it has found in German and foreign collieries. Since 1903, when the first plant was built, 60 large equipments fitted with Siemens-Ilgner fly-wheel sets have been installed, aggregating a combined lifting capacity of 40,000 tons within a period of 8 hours. Most of these plants are designed

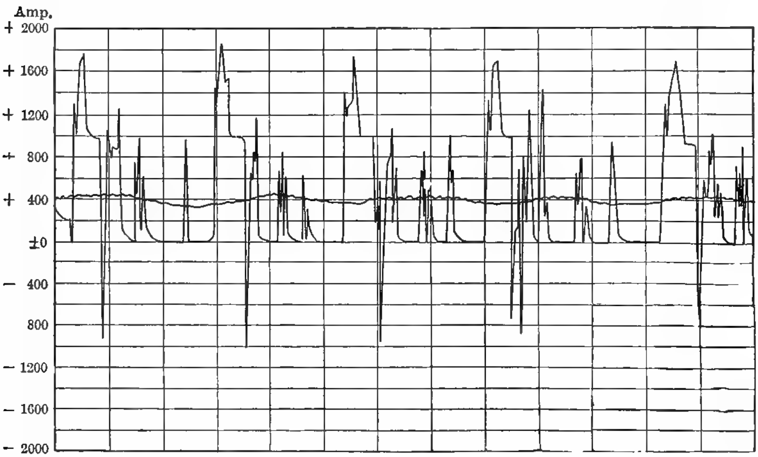


Fig. 153. — Diagram Showing Load Fluctuations or Demand for Current on Electric Hoisting Motors, and Power Consumption of Motor-Generator Set (Ilgner System).

for very large loads (5000 kg. or 11,000 lb.) and high speeds (14 ÷ 18 m. per second, or 46 ÷ 52 feet).

Diagram Fig. 153 was taken in the mine Zollern II, at Gelsenkirchen, to the power-plant equipment of which the above-mentioned data refer. They bring out very clearly, on the one hand, the almost constant power consumption of the motor-generator set; on the other hand, the extreme load fluctuations or demand for current on the direct-current hoisting motor.

On account of the extreme importance which hoisting service occupies in colliery work, being the alpha and omega of operation, I add the views of one of the best authorities on the subject, who has investigated the question of steam versus electric hoisting engine both from the economic and technical standpoint. In

addressing the Verein Deutscher Ingenieure, Prof. Ad. Wallichs, at the end of a very elaborate examination of the problem, arrives at the following résumé:

"None of the two modes of drive deserves preference for all cases, but on collieries which are equipped with steam-generating plants, modern steam hoisting engines should be installed. Where energy can be derived from blast-furnace works, or where electric current can be generated at low cost from available coke-oven gases, there the electric hoisting engine will preserve and extend its field of usefulness; also at side pits, which are located at great distances from mining centers and where the instalment of special boiler plants would not pay. Further, when hoisting from great depths under conditions such as prevail, for example, in the Transvaal, there electrically driven hoisting engines are preferable, alone for the reason that the supply of energy can be conducted (in cables) much better to engines doing underground service."

It is seen that for the case under discussion, collieries having coke-oven plants attached to them, or having some other supply of cheap fuel, electric centralization and generation of current in coke-oven gas-engine generators is advocated as the most economical method to pursue, and one which in all-round reliability is equal and in special phases of operation even superior to direct steam drive.

OTHER SERVICES

Electrical Haulage.—M. F. Peltier gives the following interesting results of experience with an electrical mine haulage plant installed at No. 3 mine at the Peabody Coal Company, Marion, Illinois:

Prior to installing electric haulage, there were sixteen gathering mules and seventeen mules working in spike teams, pulling from the lyes to the shaft, producing 1400 tons of coal daily. Owing to the size of cars, grade, and average haul of 1800 ft. from lyes to bottom of shaft, the output had reached its limit with mule haulage, and it was finally decided to install electrical haulage. Two 15-ton traction locomotives with double-end controller and trolley poles of the reversible type were installed, with No. 4-0 trolley wire, securely fastened to roof with trolley hangers, 8 in. outside of outer rail. Each locomotive is provided with two motors wound for 250 volts, and exerts a draw-bar pull of 8200 lb.

on the level. They have pulled seventeen loaded cars up a $2\frac{1}{2}$ per cent. grade, 1200 ft. long. These cars weigh when empty 1950 lb. and hold on an average of 6600 lb. of coal. So the weight of a loaded train would be over 72 tons.

The track gage is 42 in. The track measures 9000 ft. over all and is laid with 40-lb. T rails, bonded and cross bonded for the return current.

The coal is all caged on one side, and the empty cars taken off on the other. The electrical power for operating the motors in the mine is supplied by a 175-kw. generator belted to a 200-h.p. high-speed steam engine, located in the power-house department of the building containing the hoisting engines. The generator also furnishes light for the underground haulage ways. From the switchboard in the power house the current is transmitted over a 400,000 circ. mils. cable running down the manway and to the main haulage way of the mine.

The entire electrical equipment, including generators, costs $21,172.79. The average cost of hauling with mules was 2.4 per ton mile, and with electricity is 1.4 cents, the latter figure taking account of interest on investment, depreciation, and taxes, while 2000 tons of coal are daily handled instead of 1400 tons, which was the limit of mine capacity with mule haulage.

Fans and Compressors. — Fans, which are now preferably installed underground, and compressors both offer favorable conditions as far as station-load factor is concerned, on account of the continuance in service. When the compressors are operated by three-phase current motors from the high-tension line they must embody provisions to vary the quantity of air output according to momentary requirements, but without varying their speed. This is done by simply arranging an automatic by-pass from the pressure to the suction side of the compressor, through which part of the air is returned during the delivery stroke. A compressor of this type is operating on the "Rheinpreussen" mine, in Germany, having an output of 8000 cu. m. per hour (282,400 cubic feet).

CLEANING OF COKE-OVEN GAS

A few remarks concerning the purification of coke-oven gas for utilization in gas engines must still be added.

According to Reinhardt the gas at disposal for this purpose

has already been so far purified by the recovery of by-products that, as a rule, only the remains of tar, and also sulphur and cyanides, have to be removed. The tar residues are removed in so-called tar separators, which consist of high cylinders of boiler plate in which a number of platforms or ledges are arranged alternately to the left and to the right, so that the gases pass through in a zigzag direction and the tar is deposited on the ledges. Other apparatus work in a similar manner, the main stream of gas being divided into a large number of smaller streams, and by the resulting sudden alterations of direction, and also by impinging on the plate walls, the gas is freed from tar (Pelouze apparatus). Further, rotary cleaners are in use, which serve for the separation of ammonia, naphthaline, cyanide, and sulphureted hydrogen, and according to the form of the rotating surface are arranged as hurdle, brush or ball washers (patented by Zschocke). The Theisen washer can also serve this purpose; but, as far as the author is aware, it has not as yet been so employed. The inventor hoped to obtain good results, especially in the separation of tar.

The separation of sulphur and cyanide is, according to Professor Baum, best obtained by filters. The filtering material employed consists of Laming composition, a mixture of bog-iron ore and wood shavings. The composition in layers of 6 in. to 8 in. deep is carried by plates or gratings; the gas passes through two to four such layers, one after the other, and the iron combines with the sulphur to form iron sulphide, and with the cyanide to make iron cyanide (Prussian blue). The composition is from time to time taken out of the filter and exposed to the air, by which means the sulphur is oxidized and the composition regenerated and ready to be used again.

In passing through the filter not only the sulphur, but also the tarry liquors, water and heavy oils remain behind. For this reason plants which do not require the removal of sulphur often employ filtering apparatus, the Laming composition being replaced by sawdust or wood fiber. Gas holders which are frequently placed as near as possible to the engines, and, as in the case of blast-furnace gas, at the same time regulate the pressure, also serve to dry the gas.

With reference to the purification and its influence, the following may be seen from the answers to the questions which Mr. Reinhardt submitted to a number of collieries in Germany:

Of fifteen collieries which were questioned, two had no special plant for the purification of the gas, but only a plant for the recovery of the by-products — four collieries have plants for the separation of sulphur and tar, six similar plants for sulphur only, and three a plant for tar only. The power expended is only that necessary to overcome the resistance of the gas passing through the purifier, which is on an average about ¼ per cent. of the power developed. The other working expenses consist only of the renewals of the filtering material, which amounts on an average to about 0.03 pfennig per cubic meter (0.2 cent per 1000 cu. ft.); whilst the expenses of the purification plant itself greatly increase with the sulphur in the gas.

Only traces of tar have to be removed by the purifier, but it is much more important to remove the sulphur, which attacks the cylinders, piston rings, piston rods and stuffing boxes. In one case it is stated that the percentage of sulphur was reduced from 5 g. to 0.7 g. per cubic meter. The heating value of coke-oven gas varies from 2500 to 4600 calories per cubic meter. The amount of gas available for gas engines also varies extraordinarily, ranging from 3¼ to 50 per cent., according to the quality of the coal used, and, above all, according to the type of coke oven.

From the answers received from the collieries, engines using coke-oven gas require cleaning after similar periods to those using blast-furnace gas.

Generally speaking, however, at present the collieries have not sufficient experience to answer this and other questions authoritatively. The traces of tar in coke-oven gas, which are difficult to remove and to burn, probably necessitate more frequent internal cleaning; and, above all, the piston rings, stuffing boxes, oil holes and other similar parts require greater attention.

Conclusions as to Cost of Operation

Having analyzed the reasons which have led to the introduction of central electric drive for small as well as for medium-size and large machinery in combined collieries and coke-oven plants, we are now in a position to arrive at somewhat more definite conclusions as to the cost of operation and equipment. Obviously the only correct indicator for measuring the consumption of power, in case of steam drive, of both the central and the

scattered mode of driving is the feed water of the boilers, since it is only in this item that all losses are included. With scattered steam drive, or, better, with semi-centralization (since almost all plants possess nowadays a small central station for lighting and small power demands), and modern engines distributed over the works, an average consumption of 17 kg. (37.4 lb.) per effective horse-power per hour can be assumed. For older plants 24 kg. (52.8 lb.) or even higher would come nearer the truth. Electric centralization of the complete power demand will reduce the consumption to an average of from 8 to 10 kg. (17.6 to 22 lb.) per effective horse-power per hour, so that a saving in steam of at least 7 kg. (15.4 lb.) per effective horse-power per hour is attained.

Now comparing the respective operating cost of central versus scattered gas drive, it is obvious that the saving in gas consumption, which in this case is the proper indicator for the efficiency effected through centralization, will be much smaller, indeed almost nil, for the simple reason that there is no marked difference in the economy of large and small gas plants, the difference in favor of the larger being only one of first cost of equipment per horse-power. Condensation and stand-by losses, which constitute such an important factor in scattered steam drive, are also entirely absent. So the greater economy of gas-power centralization is chiefly based on superior reliability of operation and reduced expenditures for skilled labor in the central power house.

It is certainly short-sighted policy to promote the multiplication of the possibilities of breakdowns by advocating the installation of gas engines which will give complete satisfaction only when properly cared for, at places where it would not pay to keep high-class attendance. It must be repeated that for operations in the iron and coal industries the proper place for the (large) gas engine will be in the future, and is even now, in the central station. For certain departments, such as hoisting at main pit, the gas engine of standard design, owing to its peculiar working process, is anyhow entirely unsuitable as at present constructed.

COST OF INSTALLATION

While it is now generally conceded that electric centralization is cheaper in fuel consumption and other operating expenses, attendance, lubrication, waste, regardless whether gas or steam

is employed, there is still the widespread opinion prevailing that the first cost of installation is higher than with direct drive.

We have discussed this phase of the subject in the preceding paragraphs as far as the separate departments, pumping, hoisting, compressing, etc., are concerned. We can now sum up the situation in the entire plant as follows: While the initial cost of electromotors employed in the various sections is undoubtedly cheaper than with scattered steam-engine drive, and while there is a considerable saving in the size of boiler plant which can be built smaller on account of the saving in steam consumption, yet the total first cost of equipment is for centralization still higher than for direct steam drive.

Iffland estimates that in a colliery with normal water influx and depth of mine the power demand during the day averages 1 or 1.25 h.p. effective per ton of output. Assuming that output to reach 1500 tons a day, and figuring on 1 h.p. per ton, then there are rendered $1500 \times 24 = 3600$ horse-power-hours per day, or, counting holidays half, $33.2 \times 3600 = 12{,}000{,}000$ horse-power-hours per annum. With the saving realized above, of 7 kg. (15.4 lb.) per effective horse-power-hour, and assuming a sevenfold evaporation and boiler coal to cost 8 marks or \$1.90 per ton, the annual saving in coal consumption amounts to $\dfrac{12{,}000{,}000.7.8}{0100.7} =$ 96,000 M. or \$23,000. To this must be added the saving in firemen, in salaries for engine attendant, lubrication, etc., so that the total saving runs up to at least \$25,000 per annum.

The initial cost of a complete central electric equipment for a plant of this size, and including full reserves in the power house, will run, in Germany, by from \$36,000 to \$72,000 higher than with direct steam drive of all large machines and central generation of power only for the smaller ones. It is seen that under these conditions the higher first cost of complete centralization will be paid for by the savings realized in operation within one or one and a half years.

When gas engines are employed it is difficult correctly to estimate the gain in operating cost due to reduced attendance, and also to determine what saving in initial capital outlay will result from the elimination of special prime-mover equipments in the different departments and their reserves, which a careful management must provide; further, from the employment of

cables instead of gas-supply pipes throughout the works, and last, but not least, from *the elimination of the boiler plant.*

RESULTS FROM ACTUAL PRACTICE

In concluding this discussion I will add a few results which were attained in one of the earliest coke-oven gas-engine installations on the European continent, namely, that at the Borsig works, of Upper Silesia, Germany, which has been in successful operation since 1902.

In the Borsig works there are altogether 76 coke ovens with a capacity of from 6.2 to 6.5 tons per oven and a coking period of 32 to 36 hours. There are, therefore, 320 tons of coal coked in 24 hours. As the generation of gas per ton of coal amounts to 14,830 cu. ft., the consumption of 320 tons generates in the neighborhood of 4,745,600 cu. ft., of which 295,100 cu. ft. are used for heating the ovens, while about 179,350 cu. ft., or 74,730 cu. ft. per hour, are available for use in gas engines or otherwise.

The gas when coming from the ovens is first subjected to a treatment, whereby the by-products — tar, ammonia, and benzol — are eliminated; then it is dried in two scrubbers, filled with sawdust and *rasenerz*, which have each a grate surface of 376.6 sq. ft., and four grates. The scrubbers are operated alternately, one being cleaned while the other is working. After leaving the scrubber the gas is perfectly free from harmful impurities, so that the engine in question has been running more than a year and a half without being cleaned.

The composition and calorific value of the coke-oven gas varies considerably within a period of 24 hours. Assuming an average heat value of 370 B.t.u. per cu. ft., there are available 27,500,000 B.t.u. per hour for useful work. Taking the average consumption of a large gas engine as 8333 B.t.u., per brake horse-power-hour, the total quantity of gas available, when used in a gas engine, will give $\frac{27{,}500{,}000}{8333} = 3300$ b.h.p. Taking the boiler efficiency in a steam engine plant as 70 per cent., and assuming that 1180 B.t.u. are required to generate 1 lb. of steam, and that the steam consumption per horse-power-hour is 16.3 lb., then the same quantity of gas would give $\frac{27{,}500{,}000 \times 0.7}{1180 \times 16.3} = 1000$ b.h.p. In this coke-oven plant the gas

is, therefore, then 3.3 times better utilized in a gas engine than it would be in a steam plant, or, in other words, if 1000 h.p. are required within the works, 2300 h.p. can be distributed to profitable outside uses.

Gas Power for Electric Traction

The object of this chapter is to study the possibilities of utilizing, by efficient conversion, the waste gas energy which is liberated from the raw materials of the iron-smelting and coal-mining industries for generating the electric power required to transport by rail ore and coal from their respective mines to blast furnaces and coke ovens, and the finished goods to local markets. It is also proposed to analyze the possibilities of opening up the large undeveloped bodies of rich ore available in remote districts of the United States by improving and cheapening, through the utilization of such gases, transportation facilities, thus creating new independent iron-producing centers for the supply of those markets, which hitherto precluded the development of industries owing to the lack of suitable fuels.

The following remarks may serve to set forth the line of thought which commends a serious discussion of the above question. Assuming that the rate of growth of the demand for iron will, in the next 15 years, not increase in accumulative ratio, but in proportion to that of the last 15 years, then the iron industry of 1920 would call for fully 80,000,000 tons of iron ores and 40,000,000 tons of coke in excess of the quantities hitherto consumed in any single year. Raw materials cannot be produced *ad libitum,* but with a continuous consumption of nearly 120,000,000 tons annually must inevitably decrease and become exhausted sooner or later.

Referring to American conditions, it has been estimated that the reserve of iron ores in the Lake district (which produced in 1905 about 80 per cent. of the total iron-ore output of the United States) available for future operations, amounts to 1,500,000,000 tons of ore, carrying over 50 per cent. of metallic ores. The value of these ores, as well as of the coke that is used in the process of their transformation, is decreasing daily, while the cost of production on account of the increasing material and labor cost is getting higher every year. Since the almost exclusive concentration of operation to the one district may provoke a rapid exhaustion of

the Lake ores, which would be fatal to the continued supremacy in the iron industry of the United States, it seems advisable to direct the distribution of pig-iron production in due time to other territories, having comparatively virgin resources, and where markets for the disposal of finished goods are rapidly developing, as is the case in the western States. The Rocky Mountain and Pacific States contain many large undeveloped bodies of ore, chiefly magnetite and hematite, but owing to the distance from fuel and markets and high transportation charges, less attention has been paid to their exploitation than they deserve.

The Lake Superior districts, where immense deposits of hematite occur, but fuel is scarce, owe their controlling power greatly to the very favorable conditions of natural transportation, the ore being shipped to furnaces in the central and eastern States via the water road of the Great Lakes, being delivered at \$3 and \$3.50 per ton. But since the metallic value of Lake ores has been constantly decreasing from 68 per cent. down to 50 per cent., the factor of transportation is even there gradually assuming a more serious aspect. In the southeastern States, where iron and coal are more closely located, the small cost of transportation allows the ores to be delivered at the furnaces at a price much lower per unit of iron than the above, namely, at \$1.10 per ton. The marked westward shifting of pig-iron production is attributed, by the best informed authorities, to the rise of the by-product coking process and to the relatively high increase in iron and steel consumption in the West. Bee-hive coke does not lend itself so well to long railroad journeys and particularly to transfer from one mode of transport to another, as where a lake vessel forms part of the chain. By-product coke has some advantages in this respect, yet perhaps not sufficient to weigh heavily. The inclination to carry on coke making at the point of consumption rather than at the point of coal mining, and the ability of the process to use coking coals which have not found favor with the bee-hive oven, tends in the direction of allowing the fuel to meet the ore, rather than have the ore meet the fuel. The difficulties offered in the western districts by scanty fuel supply and high freight charges can be successfully overcome and the range of operation of blast-furnace plants can be greatly extended and the cost of production largely reduced by increasing transportation facilities, or in other words, lowering the cost at which ores and

coal can be delivered at the furnaces and coke ovens, respectively, and finished goods at the local markets.

The evolution of gas power in Europe has established efficient and reliable means of utilizing profitably for the generation of heat and power the gases which are generated from the raw materials of the iron industry as a by-product, and which were formerly wasted. This means offers the desired possibility of reducing the cost of transportation to a very low figure. The reason why the power for operating an electric railway for the transportation of raw materials and finished goods through iron- and coal-mining districts, or from one to the other, can be gained at such low cost rests, besides, with technical details, with the fact that modern coal mines and coke ovens working with by-product recovering, as well as blast-furnace plants and steel works, must, in order to work with maximum industrial economy, possess their own electric central station for generating the power to drive the various auxiliary machines like pumps, hoists, fans, motors, etc., all over the works. Practice obtained in continental iron works has proved beyond doubt that the application of gas engines as prime movers in such central stations is by far the most economical of all known methods, the total cost of operation having been reduced in actual practice to about one-third of the value of steam drive. This was discussed in the preceding chapters. By simply extending the capacity of the central stations, which is quite possible, by a judicious application and distribution of the uses of waste gases within the works, we can generate at no additional heat cost the entire energy, not only for transforming the original ore into marketable steel products, but also to transport the raw materials and finished products to their respective places of destination, provided that the latter fall within the commercial-distribution radius of the furnace plant, coke ovens, or coal mines, or all of them.

It is a well-known fact, which need not be here developed in detail, that of the total quantity of gas generated in a blast-furnace plant about 50 per cent. is required for use within the plant, including losses at the furnace top and in pipings, namely, for driving blowing engines, heating blast stoves, operating the gas-cleaning plant, and generating electric energy in the lighting station, while the rest, representing an amount of 25 h.p. per ton of pig iron produced every 24 hours, is available for outside purposes or sale.

Modern combined works often possess their own coal mines and coke ovens, where the coke is made which is later shipped to the furnace to be charged, together with the ores for smelting the latter. Assuming the consumption of only 1 ton of coke per ton of iron smelted, we need for a production of say 1200 tons a day, 1200 tons of coke. Figuring on an efficiency of transformation of 76 per cent., 1580 tons of coal are needed for making that coke. The total quantity of gas generated per ton of coking coal in Europe averages 27 cu. m., so that 442,400 cu. m. of coke-oven gas are produced within 24 hours. About 60 per cent. hereof is used for heating the retorts, leaving 40 per cent., or 176,960 cu. m., for other purposes. This gas has a calorific value of 4500 calories, and some 700 liters of it when burned in a gas engine are required for generating 1 horse-power-hour. The total available energy of such a plant would therefore be 10,500 h.p. Of this amount, about 10 per cent. is used for driving plant auxiliaries, leaving 9500 h.p. available for sale.

Without deducting an amount for other applications, there are, for every ton of coal transformed to coke in 24 hours, 6 h.p. available for other uses.

The development of modern gas producers has created a third and very powerful resource for the production of energy, in addition to what is gained as a by-product from furnaces and coke ovens. This is the utilization of inferior grades of fuel in coal mines, such as slack, residue, refuse, and minerals which drop from the conveyers and tipples; in short, all that was formerly wasted. This material, which at the average contains not more than 20 per cent. of coal, is now fed directly to the producers. In the Von der Heydt coal mines at Saarbrücken, Germany, 2100 tons of culm are gasified per month in Jahns ring producers, giving a total of 40,000,000 B.t.u.; in other words, 2.2 lb. of waste generate 7140 B.t.u. Figuring on an average consumption of 10,000 B.t.u. per horse-power-hour in gas engines, and deducting losses through natural deterioration and auxiliary requirements, 1 ton of culm generates 25 h.p. per 24 hours, which were formerly thrown away, but by the instalment of such gas producers are now available for sale or other purposes. (See Chapter XII.)

Summarizing, we have in blast-furnace plants 25 h.p. per ton of pig iron produced; in collieries, 6 h.p. per ton of raw coal, and

in coal mines, 25 h.p. per ton of waste material per 24 hours, available for covering the transportation requirements in a combined plant.

It would now be quite easy to construct an academic case and prove by mathematical analysis that the power required for hauling the raw materials and finished goods of some imaginary iron-smelting plant possessing its own ore and coal mines and collieries within its commercial-distribution sphere is fully covered from these resources, and without supplying additional fuel, that is, without extra heat cost. But calculations of this kind, unless based on actual conditions, are rarely of great value, as through the various theoretical assumptions that have to be made a number of uncertain quantities are introduced into the problem, which are apt to make the results of such an investigation rather problematical. So I prefer to discuss here some of the more technical possibilities of the proposed project.

Speaking first of the various uses to which the waste gas energy of the iron industry can be put to, I refer to a former chapter on the Utilization of Waste Gases, "In the Iron and Steel Industries" (Chapter X), wherein I have set forth such considerations as occur when deciding about the various forms of application of the waste gases for heat or power purposes within the works. I shall now compare the technical prospects of selling the surplus power which is available in the iron industry in the form of electric energy, to local markets, against using it for the transportation of raw and finished goods on railways owned by a corporation or syndicate, either traversing the iron and coal fields or running from coal mines to ore districts and the reverse.

The difficulty that confronts us in the first application is that only in rare cases will the blast-furnace plant be located in the immediate vicinity of a large city or other industrial center, offering staple markets for the profitable sale of such energy. Unfortunately we cannot place the plants in a convenient neighborhood of towns or other communities, but we must build them either near the ore mines or near the fuel supply and markets. Therefore, we have in this case first to attract other industries to locate within our iron-producing fields, in order to make them power-producing fields as well, and we have to cater to their interests so that we may find an outlet and get remunerative returns for our surplus energy. Not so when we employ such power for railway

transportation, which is a factor that must invariably be considered and solved regardless what are the local conditions and the geographical situation of the plant.

In assuming a favorable case, namely, that our blast furnace is located in the immediate vicinity of a large city to which it can sell electric power, then another complication arises. We must guarantee to our consumers, perhaps under heavy penalty, to deliver a certain amount of power regularly at all times during the season. It is known, however, that blast furnaces and coke ovens are subjected to certain unavoidable irregularities, owing largely to the quality and supply of the raw materials, to the working of the furnace, and to the condition of the pig-iron market, which might require a banking of the furnaces, and to other variations which have a marked influence on the production of gas, affecting its quantity as well as its quality and making it extremely difficult to foretell whether of the total theoretical surplus power there will be enough available to cover the maximum demand of our consumers. It is therefore necessary for the works management to introduce for the supply of outside markets a coefficient of safety; in other words, if we have two furnaces in an iron-smelting plant, and no reserves in form of gas producers, it is safe to figure only on the available surplus power from the gas of one furnace. So, as conditions now stand in the United States, we have with all our craving for economy, and with all the efficient engines at our disposal still to waste at least half of the precious gas energy by insufficient conversion, which cannot be utilized within the works. Here is where the enormous economy of the proposed application becomes apparent. We can foretell with sufficient accuracy what will be the amount of power required for transportation, but, in fact, this is immaterial, for we can utilize all of our waste gas energy for hauling purposes, because consumption and production of energy are balancing each other. If times are bad no pig iron is made and fewer materials required, consequently less power is needed for converting and transporting them. If the furnaces are in constant operation, a constant amount of ore and coal is required and their transportation consumes the total quantity of power generated. Furthermore, even if the conditions were so stable as to allow in the first application the coefficient of safety to assume its maximum value, namely, allowing the available power to be delivered in form of electric energy to

neighboring districts on the one hand, and to be utilized for operating our railway, on the other, there would still be the question to be settled which of the two forms of application offers the higher load factor.

Speaking of existing conditions, the inner station load factor of iron- and steel-smelting plants is about 50 per cent. If an electric lighting plant is attached to the central station for the supply of a neighboring city, the load factor of the branch system is barely 25 per cent. and usually lower. The corresponding item of a large railway plant is 66 per cent., and in our case by a judicious distribution of the rolling stock can be made 70 per cent. and even higher.

Finally, there is this great economical advantage about the proposed project, that it allows replacement of the steam locomotive by gas-driven central stations and substations, located along the road, if the latter extends over a wide territory. Electrical apparatus have now been developed to such a state of perfection that in a well-designed and carefully managed power station over 90 per cent. of the power in the engines is converted into electrical energy and delivered to the transmission system for the operation of cars. Of all the various items which have to be considered in the design of such power station for railway work, namely, the first cost, interest, depreciation, taxes, insurance, labor, supplies, repairs, and cost of fuel, the last named is the most important item of expense, frequently amounting to more than all other operating costs combined. Since the application of gas power has reduced this factor to one-half and even one-third of the value of steam-driven electrical central stations, it can be imagined what is the saving effected per ton mileage, compared with locomotive haulage.

Summarizing what has been said, it seems utterly absurd that a manufacturer who generates power as a by-product of operation, and requires constant energy for the transportation of his goods, should sell a small amount of such power to an unstable outside consumer at low profits and should waste the rest and, on the other hand, should buy the energy for transporting such goods from an arbitrary producer at high prices and at a risk, instead of employing all available power for his own requirements, which guarantee him a constant consumption, stability of transportation conditions, and enormous savings.

Geographical and local conditions will, of course, greatly determine the commercial feasibility of any such project. Things are most favorable, if one concern possesses ore and coal mines which are located at such distances that one power station at each end of the line, the one running on producer and coke-oven and the other on blast-furnace and producer gas, is sufficient for supplying energy over the whole territory without the employment of substations. If this distance is too long, substations must be arranged along the road, preferably to serve as collieries to transform into coke, which is later used in the Western furnaces, some of the coal that is shipped from the East. However, it is useless to dwell at length on the elaboration of these local details, as concrete figures can be given only on concrete applications, and without having a definite case in view the data submitted can only be regarded as speculative theory. I shall, therefore, rather point out some more of the commercial aspects of the proposed system.

Owing to the protective tariff, an efficient production in the iron industry of the United States and Germany, — which are now the two foremost iron producers in the world, — is only possible by combining in one hand, coal and ore mines, blast furnaces, steel plants, rolling mills, in short all that is necessary for converting the raw material into finished goods. To this same reason is due the enormous progress made in the iron industry of these two countries compared to England, where capitalists are justly reserved about investing large sums of money for improvements in the art of iron production, since, owing to the free trade, every foreign producer can at any time throw any quantity of iron on the English market. In modern combined works of such magnitude as exist in the United States and Germany, all factors are therefore under control of the management of the trust or syndicate, except the factor of transportation, which in the first country is largely controlled by the railroad companies, in the second, by the government. For various well-understood reasons, which are now being revealed to the eyes of the public, it is very desirable for the American iron industry to lay hold on this factor also, so as to be altogether independent of outside arbitrary measurements and certain of self-controlled stability of transportation facilities. If the iron industry would possess their own railroads for transporting their goods, or if

ironmasters or owners of coke-oven plants and coal mines would even (as power producers) deliver electrical energy to the railroads as consumers, they would control the situation of the iron market, instead of having to part with their profits in order to reduce tariff rates. That this view is also held by the executive circles of the American iron industry becomes apparent when glancing over the charter of the United States Steel Corporation. It confers to them practically every power conceivable in connection with manufacturing and transportation. They have the right to construct railroads and other means of transportation and to maintain and operate the same *ad libitum.*

In Germany, the prohibitive tariff imposed by the government on railway transportation of raw materials has already forced the ironmasters to approach the above subject, and in some instances has induced them to build their own electric railways, which are driven from the surplus gas energy of their works. Favorable to this practice is the growing tendency among the coal and iron interests to unite in syndicate form.

This movement gains its force from the fact that coal companies, according to the present constitution of the syndicate, are allowed to mine all the coal they need for their own consumption, over and above their allotments in the syndicate. This gives both coal and iron concerns an extraordinary inducement to unite into great trust-like companies, since the coal companies find an outlet which enables them to increase their production *ad libitum,* and the iron companies get adequate supplies of fuel, unhampered by restrictions as to amounts, prices and periods of delivery. In one case, where 34 per cent. of the value of iron ores was formerly paid to the government for transportation charges, the independent railway owned by the syndicate has effected a reduction of this item to one-half; in other cases, the saving effected was 20 cents per ton of ore delivered. It was also proposed to build a high-speed electric railway from Berlin to Vienna and to use the various iron-smelting plants located along the road as substations for supplying electric energy to the line; but it is found that, owing to the close concentration of industrial centers, there was in most cases an adequate consumption of the surplus power in the neighboring districts of these plants, so that not enough energy was left available for realizing the project.

It is, of course, understood that geographical, economical, and

governmental conditions in the United States differ greatly from those which obtain on the continent, and that territorial differences within the borders of one and the same country will often lead to different solutions in different localities. Also that where the superior facilities of transportation by boat are not available in America, low and elastic freight rates, and railways partly owned by the ironmasters, as is the case in the United States Steel Corporation, impart to the freight factor a different significance. However, the fact that in modern combined iron and steel works this factor still determines greatly their earning capacity and their chances of competition with other producers, and the other fact that the energy for transporting goods can be gained through an efficient transformation of the raw materials without any additional heat cost, remain invariably the same in any country or territory of the world. Since the application of gas power has proven successful in Europe, and since the gas-engine industry in the United States is entering into a profitable state of standardization and balance, it is desirable that the iron industry should seriously consider utilizing, in future operations, foreign achievements, in the manner proposed.

In conclusion, it may be said that there is nothing in the above project that requires the development of new inventions or the experimenting with untried devices. All the technical factors of the problem have been solved individually long ago, and it is only their proper adjustment to American conditions and their judicious combination to one great end which makes this proposition an attractive subject for the engineer and economist.

The successful development of the electric locomotive and the improvement made in the generation and transmission of high-tension electric current have opened up a new era in electric railroading, and the investing public is greatly interested in the possibilities of long-distance rapid transit, connecting great centers of population or industry in competition with existing steam railroads. The greatest objection hitherto advanced by antagonists against the realization of the scheme was that where "cheap" water power was not available and fuel must be burnt at the central station to produce power for driving the generators, then the operating expenses would become entirely too high on account of the cost of coal or other fuel consumed and of the increased labor necessary for operating the plant. It is gratify-

ing to see from the information developed above that the great iron- and coal-producing centers of the United States have inherent in them an enormous amount of energy which is latent at present, but which when rightly used and husbanded will yield from four to five million horse-power annually at no additional heat cost, and there can be no doubt but that some day it will be called upon to furnish its share to the novel equipment which will accomplish electric traction economically on a large scale.

XII

THE RATIONAL UTILIZATION OF LOW-GRADE FUELS

Geological, Economic and Technical Aspects of the Problem

GEOLOGICAL RETROSPECTION

It has been estimated by Liebig that the quantity of dry organic matter which is produced by one hectar of farm land, or meadow, or forest, in middle Europe, is approximately the same, namely, 2.5 tons per annum. The output varies according to climatic conditions and geographical location, being larger in the tropics and smaller in the arctics and in the desert regions. Of these organic susbtances, which consist chiefly of cellulose ($C_6H_{10}O_5$), 40 per cent. is carbon, so that, theorectically, the total annual coal production from vegetable materials amounts to 13,000 million tons, which is not quite fifteen times the quantity of coal actually consumed in the world's industries.

The assimilation of vegetable matter, or the formation of hydrocarbons, is accompanied by an absorption of carbon dioxide CO_2, from the air, while oxygen O_2 is liberated. If all plants were to accumulate their solar energy in the form of coal our atmosphere would soon be deprived of its CO_2 contents, since about one-fiftieth of the total amount is thus required. So nature has provided that only a fraction of one per cent. of the theoretical coal formation is actually reserved in the form of peat, lignite, bituminous coal, anthracite, oil and natural gas for the benefit of mankind. The rest emanates through natural detrioration in the form of gas and re-enters the cosmic cycle as carbon dioxide.

In contrast to this continuous process of slow combustion stands the exploiting of the world's fuel materials for men's domestic and public utilities and comforts. The kinetic energy

of coal, which the quiet evolution of centuries has gradually stored up in the sedimentary layers of the earth's crust, is squandered lavishly day by day at an increasing rate of consumption, and hardly 5 per cent. of its total calorific value is regained as heat, or light, or power. One thousand million tons of coal, and more, which are thus used in the world's industrial pursuits per annum, return to the atmosphere 1–600th part of its CO_2 contents in the form of exhaust products, and exercise an influence on the temperature conditions of the earth far greater than is usually suspected.

The same oxygen that was formed as a by-product of the assimilation of plants millenniums ago is now extracted from the atmosphere in order to support combustion of the carbonized products in boilers, furnaces and gas generators. Its total quantity corresponds approximately to the weight of fossil coal which is accumulated in the sedimentary strata. Atmospheric nitrogen, N, the third element of importance, owing to its chemical inertia, has very likely remained unchanged in the course of time.

ECONOMIC ASPECTS

The question whether an exhaustion of what we have termed our irreplaceable fuel resources is a danger for the life and prosperity of future generations can only be discussed on the basis of theoretical prognostications and speculative arguments. The other question, whether for the benefit of present activities it is wise to economize in the methods of utilization of these resources, cannot be answered but in the affirmative.

That individual, or company, or nation will be superior, commercially, to others which can get the most efficient service from the cheapest reliable source of labor, whether manual or mechanical. Never is superior talent engaged for low-class work, if there is an alternative available to get adequate help at low prices. Likewise, it is but a matter of political prudence for a nation to exploit the low-grade fuels material of the country, such as peat, dust coals and refuse, if they can be used for the generation of heat, light and power, instead of wasting anthracite and coke, and to reserve the latter coals for more profitable and important uses in the metallurgical and other industries. An efficient utilization of coal, generally speaking, tends toward the

preservation of national values, making a country self-supporting and independent on the world's markets. It also aids the prevention of hygienic abuses which, if not amended, are apt prematurely to weaken the earning capacity and the industrial activity of a nation.

The conservation of the higher grades and the utilization of the inferior classes of coal has still another aspect to it, namely, that of industrial expansion over territories which were hitherto undeveloped and of no direct value to their owners. All industries depend for their existence on the availability of some form of energy. Nor is water power, which with proper utilization can now be had almost everywhere in the world, always the agent best suited for certain purposes. Thus iron and steel works depend on the continuous supply of high-grade fuels such as anthracite, coke and charcoal for the stability of their production. Where these are not available the richest ore reserves are practically worthless. Either the fuel must be transported to the ore or the ore to the fuel.

But transportation itself, whether using steam or electricity or gas as motive power, depends largely on the availability of coal to support it, and the cheaper the fuel can be supplied the better for the railroads, for the industries and for all concerned. In those cases, and there are not few, where conditions of service have grown beyond the capacity of steam locomotives, and where electrification of trunk lines connecting great centers of population and industry is becoming an economic necessity, there the largest interest on the initial capital outlay for the new equipment must be offset by a saving in fuel cost, which is by far the largest single item of operating expense.

So from whatever point of view we look at the problem, it remains a matter of the greatest economic importance to find methods and means for utilizing the enormous stretches of lignite and peat lands, especially those located in the neighborhood of large undeveloped bodies of rich ore which abound in remote districts of the United States and elsewhere, and, either to transform the raw coals into some form of available energy which can be transmitted over long distances at reasonable cost, or to refine the low-grade fuels into superior products such as briquets, or coke, or chemicals, that they may serve as a basis for other industries to grow upon and to prosper. The question which remains

to be settled then is not *whether* we should use the inferior classes of coal, but *how* we can use them most efficiently.

The effect in a country like the United States of an enormous wealth of natural resources and of an extensive inland market which is protected against foreign competition by high tariff rates is, naturally, to advance the formation of great trust-like combines, to promote large scale production and to favor the standardization of manufacturing methods, which in turn bring large remunerative returns to a few favored individuals, resulting in a rapid accumulation of capital such as is admittedly, unparalleled in the world.[1] But, at the same time, an ample supply and an ease of disposal of raw materials and finished goods are apt somewhat to diminish the individual and cooperative endeavor of industrial circles toward the attainment of economic excellence in the utilization of inferior products and of such as promise no immediate large returns on the capital invested for their exploitation. On the other hand, scarcity of supply, and the necessity to face competition and the urgency to conquer markets at home and abroad, will justify and promote every legitimate effort on the part of manufacturers and consumers, aided by a judicious administration, to procure the best service from the lowest grade of sufficiency.

It is evident, therefore, in some smaller European countries, for instance in Germany, where we are supporting over sixty million active people on a territory four-fifths the size of Texas, and where the available fuel resources, especially the high-grade ones, are quite inadequate to meet the demand, that the art of utilizing inferior classes of coal, or oil, or refuse must have been cultivated to a higher degree than anywhere else. Thus the very poverty of a country becomes ultimately a source of income to its inhabitants by stimulating the manufacture and the sale of highly efficient apparatus, machinery and processes, and even of skilled talent, to foreign people and markets.

Hence it seems reasonable to conclude further — with due consideration in the different countries of the geographical, economical and governmental differences and of the differing

[1] It is interesting to observe that 25 per cent. of the business wealth of America is now under corporate control and that seven-eighths of the country's wealth, seven hundred billions, is owned by less than one per cent. of the population.

industrial policies — that the evolution of that branch of industry with which we are here concerned, will take in the large and scarcely populated countries a course similar to the developments it has taken in those that have to support the largest number of people per square mile of area.

With these and other considerations in mind it would seem a very wise policy of President Roosevelt's administration to aim toward preventing the passing of the coal lands of the United States into private ownership and the control of corporations.[1] Of the advantages claimed for the proposed leasing system there are three that bear closely on the subject with which this chapter is purported to deal: (1) Government control will prevent waste in the extraction and handling of fuels. (2) It will permit the Government to reserve from general use fuels especially suitable for metallurgical and other special industries. (3) It will enable the Government to protect the public against unreasonable and discriminating charges for fuel supplies.

TECHNICAL CONSIDERATIONS

Turning to the technical aspects of the problem, it is opportune first to get a clear idea of the meaning or the signification of the term low-grade coal. What does it imply? There is no standard of designation to refer to and none to establish. We cannot graduate the place allotted to each fuel by its relative heat value, nor can we fix its rank in the scale according to the measure of volatiles contained. The transvaluation of by-product values — to adopt an expression of Kant's — that is, the constant change in the appraising of, or in the amount of returns realized from the sale of chemical and other by-products which are gained from the various coals, and the constant improvements made in the refining and briquetting of raw materials, make it impossible to define clearly the limits below which a coal becomes inferior.

If, owing to their low carbon, high moisture and high ash contents, we speak of lignites and peats as of low-grade coals, we are following traditional customs rather than plain facts based on recent developments. Likewise there are conditions under

[1] It is estimated that already about one-half the total area of high-grade coal lands in the West is under private control. Thirty million acres are left for the Administration to take action upon.

which the smaller screenings or sizes of a high-class lean coal may rank equal or lower in monetary value — for instance coke-dust and anthracite-dust which sell at about one-tenth of the price that corresponds to their heat value — than the fuels quoted above. It is only refuse such as culm banks and other waste, which are obtained in very large quantities in coal mining pursuits and which hitherto escaped utilization entirely owing to their excessive ash contents (up to 65 per cent.), that we can rightly speak of as low-grade coals, since both their contents of fixed carbon *and* of volatile hydrocarbons is small.

EFFECT OF ASH, MOISTURE AND VOLATILES

Generally speaking, ash and moisture in coal have the disadvantage that they displace valuable combustible matter, thereby reducing the heat density of the fuel, that is, its thermal value per unit volume or space occupied. This inert material must be paid for by the consumer, hence the cost of digging, transporting and handling it must be charged against the coal, thus making it inferior as a fuel to others that possess a higher content of combustibles. Ash and moisture introduce another disadvantage in that both absorb heat. This heat is used for evaporating the water and for bringing the non-combustible matter to the temperature of the fire and maintaining it at that point, so that less heat remains available for useful purposes.

In boiler work ash acts not only as a diluent, reducing the heating power of the coal on the grate, but as an actual obstruction to the combustion process, the effect of its presence being thus doubly harmful. When analyzing some characteristics of coal as affecting the performance with steam boilers, W. L. Abbot found that when the ash contents of the coal (screenings of various size) had been increased to 40 per cent. the coal could still be burnt and would heat the water up to the boiling point, but it would not produce enough heat to make steam. So when heating boilers the useful effect from the fuel drops to zero with 40 per cent. of ash, notwithstanding the fact that the other 60 per cent. of the composition is pure coal. It is remarkable that, although over half of the composition fed to the fire is fuel, it burns without producing any useful effects.

In producer work these drawbacks are not only less felt than with grate firing, but they are actually turned to advantage.

Bulk of apparatus and heat radiating surface are factors of secondary importance with producers. They only serve as the central means for making a suitable gas which is used subsequent to its generation and outside of the producer for heating, lighting, or power purposes in regulable quantities according to the momentary demand. Heat that may radiate through producer walls or pipings can be used in a convenient manner for preheating either the combustion air or the coal or the water or what other constituents may participate in the gasification process.

High ash contents, though increasing the dust contents of the gas and producing clinkers and slag when unduly heated, will promote an even flow of the material through the apparatus when properly treated. Of course, it is preferable to reduce the contents of incombustibles in a coal by washing or briquetting if there is an alternative to their use as raw fuels at the spot, since this will lessen the amount of handling and poking required. Also, is it obvious that the higher the quantity and the quality of combustibles in a coal and the more uniform its size, the greater will be the capacity and the efficiency of the producer plant, and the more uniform the composition of the gas rendered.

But where it is necessary or desired, for reasons of economy instead of refining and selling the coal, to use it in its original raw shape at the mines at the lowest possible cost and with highest efficiency, then excessive ash contents cannot be regarded as a limiting condition, when producers are employed. In Germany we have been gasifying mine culm, a material containing hardly 25 per cent. of combustible matter and up to 65 per cent. of ash, in Jahns producers for the last four years with entire success.

Moisture, up to a certain percentage which varies with the type of producer used, is not detrimental either. Water, regardless of whether it is supplied with the coal, or with the air, or in the form of steam, acts in one way similarly as the water does in the cooling jacket of a gas engine, namely, as a preventative to excessive temperatures, thereby enabling the working process to be performed without interruption. Excessive temperatures, besides promoting the fusing of the earthly constituents of the charge to slag, are harmful to the materials of the producer wall and grate. With proper adjustment of the steam supply, where steam is added, it is possible to prevent the formation of big lumps of clinker with almost all grades of coal.

Water vapor, besides increasing the efficiency of the producer by reducing temperatures all around, when drawn through the incandescent zone or otherwise sufficiently heated, will even serve as a fuel element, enriching the gas by an addition of hydrogen and oxygen. Hydrogen, within certain limitations, is a desirable constituent because it increases greatly the calorific value of the gas and promotes flame propagation. Oxygen will combine with carbon to carbon monoxide and is desirable because it replaces a certain weight of air with its accompanying nitrogen. Nitrogen is an inert diluent, chemically speaking, being of little use to the gas. In the gasification process, however, nitrogen plays no unimportant part since it acts as an equalizing and transmitting medium, absorbing heat in the lower incandescent zone and yielding it again to the upper layers of coal on its way to the discharge duct. It can be taken, approximately, that two-thirds of the total physical heat are thus conveyed by the nitrogen through the apparatus in up-draft producers.

The fact that the moisture in coal absorbs part of the heat of gasification is an advantage in producer work, while it is a drawback in grate firing. Moisture is harmful only when large quantities of it are contained in the gas as produced. This water vapor must be removed from the gas either by dry scrubbing or cooling or compressing, else it will reduce the heat density of the gas and, when the coal contains sulphur, it will produce a corrosive action in washers and pipes, besides having a destructive influence on furnaces and in the steel-making process.

When dry coal is gasified we obtain temperatures in the gas between 600 and 800 deg. centigrade. When the coal is wet, or when water is added, we get temperatures of from 400 to 500 deg. Hence there is a smaller loss through external cooling of the gas and radiation in the piping. It should be remembered that only a small portion of the total heat that is lost by radiation can be used for regenerative purposes in the producer. Also that it is desirable for all purposes, except when producer and furnace form one unit, to have the gas leave the producer as cool as possible.

If we can control the amount of moisture participating in the gasification process, for instance by regulating the admission of steam to a comparatively dry coal, there is an economic maximum for each material which we must not surpass. In one

particular case in England it was found that the use of steam over and above that required to saturate the blast at 60 deg. would not lead to higher thermal efficiencies. This will hold true for one kind of fuel only. When using raw fuels of the lignitic and peat class we have to contend with a certain percentage of moisture which cannot be expelled from the air-dried coal except at high temperatures or by briquetting. Therefore so much water must partake in the gasification process, and the question arises: what are its effects, and how can we utilize it most advantageously?

The fact is that fuels with some moisture contents and fat coals, which absorb part of the heat of the gas in the distilling zone for driving off the volatile compounds and for splitting them up into stable constituents, are actually superior to lean coals like anthracite and coke as regards efficiency of utilization in gas producers. They also possess this advantage that the gas made contains luminous substances which greatly facilitate the adjustment of gas-fired furnaces. Fat coals are only inferior to lean ones in that they are apt to change their volume and shape in the producer while being heated, therefore requiring more frequent poking. Also, when exposed to the atmosphere they will, during storage, lose about 1.7 per cent. of their gas contents in one week, thereby reducing the output of gas and by-products, if the latter are recovered.

Attention is called to the interesting experiments of Dr. Wendt made in Germany in which he determined the relative efficiencies of producers working with and without an addition of water. Ordinary boiler coal of high volatile contents was used. When gasifying coals containing much pure carbon a greater difference in efficiency was noted between the dry and the wet process than with others, also a greater difference in the sensible heat of the gas which may be lost through radiation and cooling.

With dry gasification of pure carbon there is, theoretically, 70 per cent. of the heat value of coal contained in the gas as produced, with wet gasification 85 per cent. In the first case the sensible heat of the gas when leaving the producer is 29 per cent., and in the second case 9 per cent., of its calorific value. In practice the heat value of dry producer gas ranges between 900 and 1100 calories (100 and 123 B.t.u. per cu. ft.); that of wet producer

gas between 1100 and 1400 calories (123 and 157 B.t.u. per cu. ft.). Higher values are the result of momentary, not of normal conditions in the producer.

As for the principal constituents of the gas the analysis shows, approximately, 32 per cent. CO for the dry process and 25 per cent. for the wet one. The contents of hydrogen is 8 per cent. and 14 per cent., and that of nitrogen 60 per cent. and 50 per cent. respectively. Carbon dioxide ranges up to 3 and 4 per cent., Methan from 1 to 3 per cent. Besides there are traces of acetylene, oxygen, etc. So moisture in producer fuels acts practically as a transformer and distributer of heat, reducing the sensible heat of the gas but increasing its calorific value and heat density, thus making it better fit for outside distribution.

While for gas engine work there is a rigid limit to the hydrogen contents of producer gas drawn by premature ignition troubles, there is little accurate knowledge available on the question whether high hydrogen contents is harmful when the gas is used for heating regenerative furnaces. Some contend that at temperatures beyond 1500 deg. centigrade dissociation plays no unimportant part and that the quick destruction of furnaces is the result of high hydrogen contents in the gas. Others maintain that it is the water vapor accompanying the hydrogen which is responsible for the damage wrought, and that a high content of CO is more desirable when a soft reducing flame is required in the furnace.

With thorough utilization of the radiating heat of the gas for regenerative purposes up to 90 per cent. of the heat value of the coal can be regained in the form of producer gas. But there is a limit to preheating, the same essentially as that drawn to dry gasification, namely, the attainment in the producer of excessive temperatures which its structure and material cannot withstand. When the particular fuel used, or the type of producer employed or the manner of application of the gas commend the adoption of the dry process or of high internal temperatures, recourse may be had to external water cooling, especially of the parts neighboring on the grate, where clinkers are most apt to stick to the wall and must be removed by the poking bars.

Whenever structure and composition of the burnt material afford sufficient support to the charge and uniform access to the air, it is better in up-draft producers to leave the grate out

entirely, aspirating air from the circumference toward the center, else the passage for the outflowing material is obstructed by the central pipe and the zone of highest temperatures is shifted near the walls where it is least desired. A comparative test of the two types of producers of the same general dimensions and gasifying the same inferior grade of coal, both having water sealed bottom, the one, No. 1, working with the air supply from the center, the other, No. 2, from the circumference, but both at the same pressure, showed the following results: No. 1 gasified 7 tons of coals in 24 hours leaving 30 per. cent of slag, No. 2 gasified between 10 and 12 tons in the same time, leaving only 11 per cent. of slag. Unfortunately different fuels offer such widely differing characteristics that it is impossible to pronounce one form or construction as best suited for all coals.

American manufacturing methods are noted for their labor-saving methods, and typical for their relatively standardized output and their dislike of changing production. In this most modern branch of industry, standardization will fail to effect results such as can be realized in other departments, because when building producers manufacturers must be prepared to meet, by adaptation, separately for each individual case, the wishes and demands of their consumers which, in turn, are dictated by the cheapest fuel available in the particular locality.

Automatic charging is an illustration. Laying aside the fact that it increases greatly the dust contents of the gas, there is this misapprehension prevailing among men not familiar with producer practice, that these devices have the same general effect as automatic feeding has in boiler work. They are supposed to eliminate the employment of manual labor, thereby reducing the cost of the operation of the plant to a minimum. This is only so with coals that do not require treatment subsequent to their feeding to the producer. With the bad caking variety, which abounds in this country, the constant poking required represents a much greater amount of manual work than the charging process proper. So in this case, except perhaps in very large plants, there is no saving realized through automatic charging unless mechanical poking is adopted at the same time. The question is again strictly one of locality, size of plant and kind of fuel used.

Though, as we have seen, there are limitations to the efficiency of the conversion of the kinetic coal energy into gas,

yet the gasification of coal in producers is superior in almost every respect to grate firing. One reason which has not been mentioned is that in producers complete and smokeless combustion can be attained with a surplus of 20 or 30 per cent. of air beyond the amount that is theoretically required, while with grate firing a surplus of air of from 100 to 250 per cent. over the theoretical maximum must be expended in order to attain the same result. Hence by far the largest portion of the heat that is generated on the grate is lost on account of the high temperatures at which the products of combustion leave the flues. Therefore, the larger the quantity of products of combustion per unit fuel the less efficient will be the utilization of the combustible material when grate firing is employed, while with producers this deficiency can be more nearly compensated.

Enough has been said to establish that high ash and moisture contents in a coal do not preclude its utilization in gas producers, and that the utility of these apparatus ranges far beyond the realm of application of grate, furnace and boiler. Of course, if we come to raw air dried lignites and peats containing over 50 per cent. of water, then direct gasification becomes difficult, even when thoroughly preheating air and fuel, and we have either to admix a certain weight of dry coal to the raw fuel or we must briquet it, whereupon the commercial distribution radius of the fuel and its range of application is extended somewhat in proportion to its increased heat density, regularity of form and composition.

EFFECTS OF BY-PRODUCT COKE MAKING

Taking up another phase of the subject: it is through the logical application of approved methods of the utilization of the higher grades of coal to the exploiting of the lower species that we have come to abandon the traditional and wasteful practice of appraising the coal according to its heat contents and of utilizing its fuel value only, but now, before destroying coal we analyze it as to its chemical and other values. We are actually doing the same with peat now that progressive industries did long ago with coking coal in by-product recovery ovens.

The resulting advantages, it is remembered, for the coke-making industry were twofold: An increase of from 5 to 10 per cent. in the yield of coke, and a return from the sale of by-products

varying from 75 cents to $1 per ton of coke made. Yet some countries even to-day are reluctant to change their conservative attitudes toward this only rational process. Take the case of England. If the total quantity of coke made in the United Kingdom for metallurgical purposes is reckoned at 10,000,000 tons, at an average price of $3.30 per ton, the general adoption of by-product coke ovens would result in a saving of from $1,750,000 to $3,500,000 derived from the increased yield of coke, while up to $10,000,000 could be derived from the sale of the by-products, provided that the intrinsic value of the latter would remain the same in the future as it is now.

In Germany by far the largest quantity of coke is now made in modern ovens, since owing to the high development of our chemical industries we possess staple markets at home and abroad for the disposal of the by-products which yield us an annual gain of some $10,000,000. We are just beginning to adopt the same process for the utilization of inferior fuels such as lignite and peat, whenever by-product recovery can be carried out on a large enough scale to make it a commercial success. Thus peat from the moorlands of upper Bavaria is subjected to a process of destructive distillation in Ziegler furnaces yielding besides coke and gas a number of valuable by-products. The coke is used for metallurgical purposes and as a substitute for charcoal; the gas for heating, lighting and power purposes. Of the chemical by-products sulphate of ammonia is used as a fertilizer in agricultural pursuits: tar oil, creosote and paraffin serve a variety of useful purposes. So what we do in this case is to split up the coal into a number of separate constitutents of which each may serve a different purpose and each may fetch a better price than the original material.

COAL TAR OILS

Among the efforts made in Germany to derive all products which are necessary to support the national industry from its own native resources and without the aid of foreign imports, the activities in the lignite industry are the most noteworthy. It is remarkable how the production and valuation of this fuel which is commonly known under the name of brown coal has increased within the last fifty years.

At the beginning of that period, in 1865, lignite held about

the same rank as peat holds now. The State of Prussia at that time produced 18.6 million tons of coal, valued at 25 million dollars, and 5 million tons of lignite estimated at 3.5 million dollars. By 1905 we find a production of 113 million tons of coal, worth nearly 250 million dollars, and 44 million tons of lignite worth 25 million dollars. The latter figure refers to the fuel value of lignite, not to the price that may be realized from it including by-products such as paraffin and brown coal tar oils.

These oils and others gained from hard coal tar, from caking coal and from bituminous slate are getting more and more valuable since it was demonstrated that they can be used successfully as fuel in Diesel and other oil engines. The annual production of paraffin oils gained from brown coal tar has reached within the last year the figure of 40,000 tons, selling at prices from $19 to $26 per ton. The production of oils gained from hard coal tar, such as creosote oil and anthracene oil, amounted to 84,000 tons within the same period and they were sold for purposes of power generation at the very low price of from $6 to $12 per ton, according to locality. Another interesting product of the coal gas industry is benzol. As a fuel it is fast replacing gasoline and alcohol for automobile and motor purposes, since besides costing only half as much it is more economical and safer in operation.

The possibility of gaining from lignitic and other coals and from peat a series of substitute fuels for the ordinary crude oil and petroleum is of great importance even for the future activities of the United States, though this country is apparently very well supplied with raw materials of every kind, especially with oil, marching as it does at the head of all oil-producing countries with an imposing output worth almost a hundred million dollars per annum.[1]

Yet there stands this incontrovertible fact that oil wells have

[1] In considering the relative values of the mineral and metallic products of the United States, it is found that the fuel materials aggregate about $650,000,000 annually, which nearly double that of the output of pig iron, and about six times the value of the various precious metals produced. Of this enormous sum, which represents about 40 per cent. of the total mineral production of the country, only about one-seventh, or $95,000,000, must be credited to the output of oil, while over one-half is represented by bituminous coal, one-quarter by anthracite, and one-twentieth by natural gas. An interesting fact often lost sight of is that the oil output in the United States has a greater total value than silver and gold together.

been tapped so recklessly in the past that the center of production was shifted from Pennsylvania to California, the extreme west of the country, leaving little territory for further exploitation. And there is the other fact that the remaining wells are practically all in the hands of one private corporation, leaving little chance for the Government to establish a control of the kind that would prevent said corporation from selling out such oil immediately and with no regard for future national activities.

The enormous extent and the policy of the business which the oil trust has been doing during the last 24 years with the American product can best be realized from the report which the Commissioner of Corporations has recently submitted to the United States Government. Comparing the prices of crude oil with the prices of refined oil and its by-products to ascertain whether the margin between the raw and completed product has been reduced by the improved methods and better organization of the trust, the Commissioner finds that this margin, instead of decreasing, has increased from 6.6 cents per gallon for 1898 and 1899 to 7.7 for 1900 and 1902, and 8.4 cents for 1903 and 1905. Naturally an increase has also taken place in the annual profits of the Standard by reason of this price policy, amounting from 1896 to 1904 to over $27,000,000, while the entire net earnings from 1882 to 1906 — based on an investment worth at the time of its original acquisition not more than $75,000,000 — were at least $790,000,000, and possibly much more.

These figures prove clearly that the beneficial effects of private monopoly power on the national industry and the absence of normal competition are not always what they are claimed to be by their defenders. "The Standard Oil Company," says the report, "gives the public none of the benefits of its superior efficiency, but, on the contrary, charges prices higher than those which would exist in the absence of such a combination." And, we must add, what is worse for America: the rich veins of this colossal country have been emptied of their precious contents — an irrecoverable loss — and the oil, by the manipulations of that company, has been squandered all over the world where it has served and is still serving to support and build up competing industries and skilled talent. In the meantime foreign countries whose natural resources are exploited under the supervision of the government have preserved their store of oil, small though

it may be, and are beginning to lift it now, at a time when its intrinsic value as a raiser of by-products for a variety of industries is being understood, appreciated and duly compensated. It is only when people lack technical training and industrial forethought, or when they have nothing but the immediacy of earnings at heart, that they fail to recognize in the gross exportation of fuel materials from a country a dangerous depletion of its basic resources, working injury to the national welfare.

The increasing importance of oil in naval activities is known. An ample and ready supply of it for purposes of national defense is desirable. The event of the utilization of tar oils gained from coal under the control of the Government will prove a more effective restraint to the monopolizing of the oil business by the Standard Oil Company than the appointment of receivers or indictments by the hundred brought by the Federal grand juries against that corporation and the payment of fines exceeding even the thirty million dollar mark.

LIGNITE AND BROWN COAL BRIQUETS [1]

Another event which is bound to increase largely the value and industrial importance of lignite lands is the transformation of the raw material into briquets. The center of the lignite basin in Germany, which is located on the left banks of the Rhine, has increased its output of raw lignite within thirteen years from 1,016,300 tons to 9,673,100 tons, that is by 851 per cent., and its output of brown coal briquets from 272,580 tons to 2,447,000 tons, that is by 797 per cent. Of this amount 1,810,000 tons are sold in Germany, 291,700 tons are exported and the rest is used in the briquetting industries. Without overestimating the value of statistical figures these data testify well enough to the increasing demand for this class of fuel in European pursuits. The sale of briquets would have been even larger if there had been no car famine.

It may be ground for comfort in the United States, where transportation is a serious factor for the briquetting industries to contend with, to know that in a country where the railroads are owned and controlled by the government, being less of a

[1] For distribution and characteristics of American lignites refer to the regular reports of the United States Geological Survey.

business concern and more of a philanthropic-national institution, such accidents will happen, though with this difference compared to America, that they befall large and small dealers alike without discrimination and without secret rebates.

The cost of the production of briquets has increased somewhat in proportion to that of ordinary coal, owing to the higher wages paid. For domestic uses they were sold last year at from \$2.25 to \$2.50 per ton, while for industrial purposes they brought prices from \$1.70 to \$1.80 per ton. The heat value of brown coal briquets ranges from 7700 to 9600 B.t.u. per pound, compared to an average of 4900 B.t.u. per pound of raw lignite containing 45 per cent. water. Their heat density is such that up to 3 tons or 60,000,000 B.t.u. can be stored in a space of 100 cubic feet, hence their commercial distribution range is almost double that of the raw coal.

One drawback to the more general application of lignite briquets in industrial pursuits rests with the fact that the smaller sizes which are best suited for producer work are somewhat more expensive to make and yet bring lower prices than the larger sizes, which are now so widely used for domestic firing. Yet they are an ideal producer fuel on account of the regularity of form and composition. An analysis of Bockwitz briquets, which contain about 80 per cent. of combustible matter and represent a fair average, shows C 53.3 per cent., H 4.24 per cent., O + N 21.95 per cent., S 1.06 per cent., H_2O 14.65 per cent., ash 5.64 per cent., slag 1.09 per cent., calorific value 4580 calories per kilogram (8240 B.t.u. per lb.). The gas generated from Bockwitz briquets in (Körting) producers shows an average analysis of: CO_2 14.8, O 0.2, H 16.3, CO 11.8, CH_4 2.0, $C_3H_6 + C_2H_4$ 0.4, calorific value 1030 calories per cubic meter (115.4 B.t.u. per cu. ft.). The briquetting tests of the United States Geological Survey show that the Dakota lignites can be treated as successfully as the German brown coal, a fact which will vastly extend the territory which these fuels control.

Producers burning brown coal briquets or dry lignite and peat, unless having means like the Pintsch producer for by-passing the volatile gases through the incandescent zone below where they are burnt, employ invariably a second upper incandescent zone. An additional supply of air preheated to about 200 deg. centigrade (Deutz), serves for the destruction of the tar, or better,

of the tar forming hydrocarbons which are decomposed together with the moisture, so that besides the cleanness of the gas there is a double gain in the calorific value of the gas made. No water need be added when the material contains beyond 20 per cent. of moisture. No operative difficulties are encountered so long as the water contents of the fuel does not exceed 28 per cent. Instead of clinker or slag a light ash is formed which is easily removed. The actual coal consumption remains in the neighborhood of one pound per horse power hour delivered, costing about one-tenth of a cent.

In water-cooled producers which can work with a high incandescent zone, using high air pressures and allowing the attainment of high temperatures, raw lignite with up to 50 and more per cent. water can be burnt directly without previous treatment. In one iron smelting plant in Germany raw brown coal, containing only 26 per cent. carbon, 60 per cent. moisture and 30 per cent. dust, and having a heat value of 2200 calories per kilogram, or 3960 B.t.u. per pound, is gasified in Turk producers, yielding a gas of 1340 calories per cubic meter (150 B.t.u. per cu. ft.).

When raw lignite is burnt in producers possessing no provisions for the destruction of tar, and when it is desired to separate out the paraffins from the gas subsequent to its generation, in order, on the one hand, to recover the by-products, and on the other, to distribute the gas for heating or power purposes, or both, it is better in large plants, instead of employing any of the well-known cleaning apparatus, to press the gas after being cooled down to atmospheric temperature through a motor-driven compressor into a double tank, whence it is allowed to flow into the distribution main without interruption. The compression and subsequent expansion of the gas will serve very effectively to separate out undesirable constituents, leaving the gas ready for local and other uses in gas engines and furnaces. For the average power plant it is, of course, not advisable to engage in operations entirely distinct from its own special field of work.

THE UTILIZATION OF PEAT

If we were to conclude from the manner and extent of the industrial application of peat within the last twenty years to its future possibilities, our prognostications would be both dis-

appointing and wrong. While the use of hard coal within said period has increased in Germany from 60 to 136 million tons, and that of lignite from 15 to 56 million tons, the output of peat has not increased at all, in fact it has diminished. The mistake that has been made is that peat was regarded and utilized as a fuel only, and not as a raiser or container of valuable by-products. Peat, since it does not allow of transportation, neither as raw material nor in form of briquets, owing to excessive moisture contents, has no market value. Hence its appraising or valuation depends entirely on the initiative of and on the course of action adopted by the owner of the moorlands. Peat to be rightly used and husbanded must be considered and treated as a material furthering the agricultural possibilities of the soil and not as a means for producing heat, light and power in varied industries, at any cost.

Agriculture is the fundamental industry of a country. On its prosperity all other industries are based. Every consideration is subordinate to the idea that the food-growing possibilities of the ground must remain in accord with the ever increasing population. The gradual exhaustion of the soil and its territorial diminution caused by the restless expansion of the mechanic industries must be compensated, on the one hand, by utilizing vast stretches of land hitherto void of cultivation; on the other hand, by supplying an ample provision of nitrogenous manure preferably from the country's own native resources.

57. It is a frequent occurrence accompanying ordinary coal-mining operations that the soil above the mines will sink and decay, becoming what we call "unland," that is, territory unsuited for agricultural pursuits. When digging peat good farm land is laid bare to the plow ready for immediate cultivation and settlement, thus causing new agricultural possibilities and values to develop. When reclaiming land covered with timber or having stumps upon it, 1,000,000 acres would cost at least $33,000,000 to clear. Peat, moreover, contains from 0.75 to 2.85 per cent. of nitrogen which can be recovered by proper treatment as ammonium sulphate, giving an excellent fertilizer.

Until a short while ago all countries were dependent for their supply of nitrates on the saltpeter resources of Chile, which will be exhausted in about forty years. Lately the production of sulphate of ammonia gained in the different countries has re-

placed the imports of Chile saltpeter to a large extent. In 1895 the consumption of imported nitrates in Germany was about 450,000 tons and that of sulphate of ammonia 100,000 tons. Ten years later, in 1905, the former rose to 540,000 tons and the latter to 215,000 tons, or 20 per cent. and 100 per cent. respectively. Yet the value of the annual imports of nitrogenous manure which is supplied to that country in form of saltpeter, sulphate of ammonia and guano from abroad amounts still to a total of some $36,000,000, which can be saved by the judicious application of up to date methods. The recovery of the nitrogenous and other products is the first essential for a rational utilization of peat.

Among the technical difficulties which are encountered must be mentioned first the low heat density of peat caused by the high moisture and high ash contents, which vary around 90 and 25 per cent. respectively. By the use of kneading and molding machines and air drying, the moisture may be reduced down to about 25 per cent. There are other methods of drying peat, for instance the electrical process invented by Graf Schwerin and others, that give more economic results than the mechanical process, but they cannot here be discussed in detail.

Another technical difficulty of peat utilization is the cumbersome task of dredging and transporting the raw material from the moorlands to the place of usage. This distance increases daily owing to the low heat value and depth of peat bogs. Even when located in the midst of moorlands, an industry that would base its operations solely on peat as a *fuel* would soon find in the cost of hauling a limiting condition, also in the fact that this very voluminous material cannot very well be stored so as to be protected against the influence of the weather, and if exposed to the atmosphere it will slack and disintegrate quickly.

Attempts to use peat for firing locomotives have failed abroad. The practical question: what does it cost to raise 1000 pounds of steam with peat compared to coal firing, has been decided by Dr. A. Franke, the foremost authority on peat utilization, in favor of coal. So here comes the gas producer as the only economical solution of the problem.

Peat with 50 and more per cent. water is now gasified in producers with the aid of highly superheated steam (Dr. Caro's patents), yielding, besides sulphate of ammonia, a power gas well suited for use in gas engines. A plant of this kind is operating

near Nordgeorgfehn, in Germany, using peat from the Marcard moor-canal, which contains 1.17 per cent. of nitrogen. Per ton of dry peat 30 kg. of sulphate of ammonia worth $1.70 and 2500 cubic meters (88250 cu. ft.) of gas of 146 B.t.u. are gained, which will yield 600 horse-power hours in gas engines besides what is used in the process. From the gas-driven electric central station current is distributed to the neighboring districts at low prices. Some peat bogs in Ireland contain in their upper, more recent layers, up to 3 per cent. of nitrogen. This means that 2 tons of wet peat could yield on an average nearly as much ammonia as 1 ton of coal. To the Mond interests the possibility of using peat instead of slack fuel in producers comes as a very welcome event, since it will help to place this process on a commercial footing also in this country.

Reference has already been made to the Ziegler process which originated from an attempt to improve the raw peat so as to give a better fuel. Now the idea is to make coke from peat and to utilize the resulting by-products in the most profitable manner. In order to accomplish this, peat with low ash contents and with its moisture expelled down to 18 or 25 per cent. as a maximum must be available. There are two systems of closed ovens or retorts employed, the one yielding a good metallurgical coke and the other one of the semi-variety. The analysis of coke No. 1, of which are gained from 8 to 10 tons per oven within 24 hours, is: C 87.8 per cent., H 2 per cent., N 1.3 per cent., S 0.3 per cent., O 5 per cent. ash 3.2 per cent., calorific value 7800 calories per kg. (14,040 B.t.u. per lb.). Of semi-coke are gained from 12 to 14 tons per oven within 24 hours, and the analysis shows C 73.89 per cent., N 1.49 per cent., S 0.20 per cent., H 3.59 per cent., O 14.52 per cent., ash 2.5 per cent., moisture 3.8 per cent, heat value 6700 calories per kg. (12,060 B.t.u. per lb.). Among the more valuable by-products of the tar are acetate of lime, sulphate of ammonia, methyl alcohol, light and heavy gas oils, which can be used partly as fuel and lighting oils and partly as lubricants, and paraffin and asphaltum. There are several plants of this type working in Germany and elsewhere, the most notable of its kind being the one built on the moorlands of upper Bavaria, at Beuerberg. It is a most interesting illustration of the modern endeavor to secure in the utilization of coals the largest returns from the lowest grade of supply.

MINE CULM, WASH BANKS, ETC.

The rational utilization of these materials is of great importance for collieries, where they are available in enormous quantities, and where they have formed hitherto a real nuisance to the works management. Owing to excessive ash contents these coals could not be burnt under boilers, nor could they be dumped back into the mines on account of the danger of causing self-ignition of the remaining coal deposits. So they were either stored up in large piles in the neighborhood of the pit, or where territorial limitations prevented this, they were transported by rail into neighboring dumping grounds, being thus absolutely useless and causing heavy expenditures. There are two possibilities of utilizing these low-grade coals: one is to gasify them in Jahns ring producers where their fuel value is utilized, the 25 or 30 per cent. combustibles yielding a gas free from tar and well suited for heating lighting or power purposes. A plant of this type was built early in 1902 on the von der Heydt coal mines, Saarbrucken, Germany, and has been in active service ever since. The gas generated has an average composition, in per cent. of volume, CO_2 12.6, CO 13.1, CH_4 0.9, H 27, O 0.57, heat value (low) 1183 cal. cu. m. (132.5 B.t.u. per cu. ft.) The cost of 1000 B.t.u. in form of producer gas is only 0.005 cent., or one brake horse-power-hour in gas engines costs 0.05 cent.

Another method is that developed by Dr. N. Caro, of Berlin, Germany. It is based on the observation that "wash banks" and other waste contain more nitrogen than that which corresponds to their coal contents. In Westphalian collieries it was found that wash banks, the coal contents of which show on analysis about 1.2 per cent, of nitrogen, contain up to 1 per cent. of nitrogen, though their total contents of combustible matter is only 25 or 30 per cent. Dr. Caro has succeeded in gasifying this material in producers of the Mond type especially equipped for the purpose, and besides getting a suitable gas he gains about 80 per cent. of its total nitrogen contents in the form of sulphate of ammonia. At the same time the sulphur is removed so that the residues of the gasification process can be directly dumped from the producer into the mines without fear of premature ignition. Per ton of wash banks, depending on their value, from 30 to 40 kg. of sulphate of ammonia are gained so that not only

the cost of removing the waste coal is recovered but, in addition, a good profit is realized.

COKE BREEZE, DUST COKE, ETC.

There are places where fuels of very small size are available in large quantities and at low prices, for instance in gas and coke works, railway stations, etc. Their high ash and dust contents and the small size makes them unfit as boiler fuel, nor are they well suited for transportation. Two ways of utilizing these coals are now open: The one is to burn them in gas producers especially designed for their use; the other is to briquet them, whereupon they become capable of competition with the best grades far and near. Here are some of the points to consider when using dust coals in gas producers: The great resistance offered by the dense fuel material to the passage of air must be overcome by keeping the charge as low as possible and constant and uniform in height, otherwise the air will pass up along the walls, producing clinkers and a bad quality of gas. The coal must be charged frequently within short intervals and in small quantities, and if containing moisture, it must be preheated by the gas as produced. This exchange of heat will increase the calorific value of the gas, at the same time lowering its temperature and that of the process. Producers must be dimensioned larger in proportion to the higher dust content of the material used. The quality of gas rendered is somewhat lower but sufficient for use in gas engines and for heating furnaces, unless very high temperatures are desired.

Producers designed in accordance with these principal considerations by Julius Pintsch, of Berlin, and by the Gasgenerator Company, of Dresden, Germany, have given excellent results with the poorest fuels. A 1000 horse-power Pintsch producer plant using coke breeze has been doing uninterrupted service, day and night, since April, 1905. The dust coke which settles in the smoke boxes of locomotives, having a composition in per cent., C 75.2, H 0.4, O + N 1.45, S 0.85, ash 19.2, moisture 2.9, calorific value (low) 6073 calories per kg. (10,930 B.t.u. per lb.) can be also used in these producers and will yield a gas of the following composition, in per cent.: CO_2 5.0, CO 26.0, H 12.0, CH_4 0.2, calorific value (low) 1100 calories per cubic meter (123 B.t.u. per cu. ft.).

As an example of how the intrinsic value and the salability

of dust fuels can be increased by briquetting, the case of the Gas Works at Riga may be cited. Large piles of dust coke which originated from breaking, handling, storing and transporting ordinary good coke were available. They had been sold hitherto as filling materials for ceilings, fetching a price of 2.5 cents for 100 pounds, while coke in the larger sizes would sell at 30 cents per 100 pounds in that locality. Though the dust coke contained from 75 to 80 per cent. of combustibles it was impossible to use it for firing boilers since the fine dust would clog up the flues, requiring frequent cleaning and causing heavy expenditures. So a briquetting machine was installed which produced 1000 brickets of 0.4 kg. or 400 kg. (880 pounds) of briquets per hour. An addition of 5 per cent. of hard pitch and tar residues as binding material gave sufficient cohesion. The average production in a ten-hour day was 4200 kg. (9240 pounds) of briquets having a heat value only 5 per cent. lower than coke, the higher ash contents being compensated by the greater heat value of tar and pitch. They make an excellent fuel for boilers and gas producers. By the adoption of superior methods of utilization the returns from this low-grade material have been increased from 55 cents realized per ton of coke dust to $3 received per ton of coke briquets.

A few words may be added regarding the activities of the United States Geological Survey and the proposed control of coal lands by the Federal Government.[1] In view of the paramount importance of the subject it is a matter of regret for the development of this branch of industry in the United States as well as for science international — noting the inadequate apparatus available at the fuel testing plant at St. Louis and considering the superior progress that has been made in the study of these commodities abroad — that the appropriation for the investigation

[1] If a committee of twenty experts chosen by the National Civic Federation after an exhaustive investigation of municipal trading in the United States and Great Britain have come to the conclusion that America, for various well understood reasons, is unripe for municipal ownership of the revenue-producing industries, we must draw the further conclusion that it is ripe for government control of its most needed resources. In Europe the method of partial ownership of public service corporations has proved very successful.

It has the advantage of effective public control while retaining the stimulus of private interest. The private stockholders can be relied on to prevent political abuses, and the public ownership assures the necessary publicity.

of fuel problems which has been made by Congress may not be expended for work outside the United States proper. A more liberal endowment of the work of the Geological Survey which would enable that body to proceed with the investigation and dissemination of fuel characteristics and conversion beyond the limits of its present equipment must seem desirable for the future stability of the American industry.

The accumulated experience of many European nations that have attempted, from time to time, to operate industrial establishments, bureaus of research and other offices under the supervision of the State, proves conclusively that when a government undertakes to own or to control institutions devoted to the public welfare and fails to supply the means necessary for bringing them up to the highest standard of excellence and for keeping them at that level it will work harm both ways. It discourages those that have devoted their best energies to the work and in the routine of labor find their efforts hampered by insufficient equipments and by pecuniary restrictions, and it destroys the faith of those among the people who do not profit by it in the efficiency of government control as a means for promoting the industrial progress and for furthering the general prosperity of the country.

IN CONCLUSION

This subject of which the above gives a brief *exposé* does not allow of narrow technical treatment. It requires breadth of vision and accuracy of knowledge to realize its economic and political bearing on the destiny of nations. One fact, however, stands out clearly: it is this, that, according to the present state of our knowledge, the rational utilization of coals of high volatile contents requires the adoption of gas producers with by-product recovery and the distribution of heat, light and power from gas-driven central stations to the neighboring districts, a scheme which is feasible only when operating on a large scale and where staple markets for the disposal of goods lie within the commercial distribution radius of the plant. Fuels of high ash contents, on the other hand, such as mine culm and other waste of low heat value, must be used at the spot in producers specially equipped for the purpose. Dust coals and similar fuels can either be gasified in producers particularly designed for their use, or they may be

transformed into briquets, whereupon competition becomes possible with the best grades of coal for all manner of application. In all cases the employment, in the electric central station, of large gas engines is a logical supplement to the gasification of coals in producers and is the only means, so far available, for attaining maximum industrial economy in the operation of plants of some magnitude.

Another fact gratifying for the engineer to see revealed is that industrial progress not only has confirmed but has passed beyond the remarkable prediction of the late Sir William Siemens, which he promulgated as early as 1881, in these words: "I am bold enough to go as far as to say that raw coal should not be used for any purpose whatsoever, and that the first step towards the judicious and economic production of heat is the gas retort or gas producer, in which coal is converted either entirely into gas, or into gas and coke, as is the case at our ordinary gas works."

VALUATION, CHARACTERISTICS AND DISTRIBUTION OF COALS

In Germany the gasification of anthracite and coke in suction producers, and the utilization of the resulting gas in gas engines, is, it was said, almost a matter of the past so far as the regular grades, nut, buckwheat, etc., are concerned. Yet it has been demonstrated that even at such high prices as $5 per ton, competition with modern steam plants (Wolff semi-portable locomobiles) is possible in the smaller sizes. But the saving effected when operating on a large scale and in competition with up-to-date steam plants burning low-grade bituminous coal is not large enough to induce power users to abandon a traditional and wasteful, but reliable, mode of power generation in favor of the new claimant. To illustrate the commercial value and importance of the utilization of low grade coals in producers for certain localities let us take a concrete case from German practice. There the price of average good gas coke is, in certain districts, about three times higher than that of lignite briquets, while its heating value is only one and one-half times higher. So the cost per unit power in producer-gas engines is from 40 to 50 per cent. lower when using lignite briquets than when burning coke.

Other conditions being equal, heat density and transportation

factor will fix a definite economic limit beyond which a certain coal from a certain mine is no longer applicable. In other words, the higher the heat density of a coal and the greater the transportation facilities, the larger will be the radius of its commercial distribution sphere, with the pit as the center.

HIGH-CLASS PRODUCER FUEL VERSUS LOW-GRADE STEAM COAL

In England much discussion is still wasted on the question whether or not these high-class lean fuels can be or should be used in competition with the lower grades of steam coal. The results of a recent test made with suction-gas producers at Derby reveal the following conditions: With Scotch anthracite of good quality the consumption is 1.1 lb. at full load and 1.6 lb. at half load, per brake horse-power per hour. The average is 1.35 lb., including stand-by losses. With coke the consumption is a little higher. The average consumption of cooling and evaporation water varied from 1 to $\frac{3}{4}$ gal. per brake horse-power. The price of equipment remains between \$46 and \$56 per declared brake horse-power, of which \$20 was the price of the producer plant proper per unit. With anthracite costing \$5.75, the fuel cost per brake horse-power runs up to almost 0.5 cent.

In Germany, as above noted, it has been realized that the question of gas versus steam is very largely dependent on the employment, in producers, of cheaper grades of coal than were hitherto used. Of the non-bituminous classes which yield a gas free from tar, only the smaller screenings, buckwheat, pea, dust anthracite, and dust coke have a reasonable chance for competition. Under certain local conditions they may even be superior to bituminous coal, lignite, and peat fuels.

To give an illustration: In a certain city gas power was to be adopted, and there were three different classes of fuel available: Anthracite nut at \$5 per ton, anthracite dust at \$1.70 per ton, and lignite briquets at \$2 per ton, having the following heating values: 7500, 7000, and 4500 calories respectively, or 13,500, 12,600, and 8100 B.t.u. per pound. The fuel consumption, including all losses, worked out at 0.25, 0.089, 0.18 cent per brake horse-power-hour for the three classes. So in this particular case dust anthracite was superior to all. It had the special advantage over lignite that the gas as producer was absolutely free from tar. Taking into consideration the factor

of transportation it was found that the cost of fuel for operation with these three classes is equal when the prospective plant is located at the following respective distances from the mine: Anthracite nut 0, anthracite and coke dust 404, and lignite briquets 73 miles. It is seen that dust coke and dust anthracite owing to their low price and comparatively high heat value have the largest commercial-distribution radius, in this case.

These figures are presented with no view of implying standards, but they are intended to show on how many variable factors the definition of the term "low-grade fuel" is dependent and also how the less marketable values of a high-grade coal may sometimes offer characteristics which justify their employment in competition with the inferior bituminous classes.

Before entering into the discussion of the processes and apparatus employed for the gasification of these fuels it will be well to get clear about their distribution and general characteristics; also to study the data pertaining to the production and briquetting of lignite and peat,[1] so far as they have not been dwelt upon.

LIGNITE

Lignite is, besides peat, the most important fuel in Germany. 48,000,000 tons of lignite (brown coal) were produced in 1905, and in addition 5,000,000 tons were imported from Bohemia. Of this total about 10,000,000 tons were briquetted, since with the high contents of moisture (some sorts contain up to 60 per cent. of water), the utilization of the raw coals would not be commercially profitable beyond the locality of their production, on account of the excessive transportation charges. The raw lignite is mined in big lumps of loose composition, which oftentimes show the original wood structure well preserved. Its heating value varies from 3000 to 6800 B.t.u. per pound, the moisture contents is about 45 per cent., in Germany. The process of briquetting the raw material consists of grinding it to a fine powder and heating the same in a double-walled cylinder by means of steam until its contents of moisture is reduced to 15 or 17 per cent. While being in this state of superheat, it is compressed at a pressure of from 21,000 to 29,000 lb. per square

[1] The corresponding data on American fuels are available in the regular reports published by the U. S. Geological Survey.

inch into the desired form and mostly without applying any binding material, since the tarry constituents contained in the fuel give sufficient cohesion. In the Rhine districts about 2.5 tons of sifted raw coal give 1 ton of briquet. For evaporating the surplus 2900 lb. of water 1.3 times the weight of exhaust steam, namely, 3800 lb., is required. This steam is generated from the waste coal which remains available from sifting the raw fuel, and from 1700 to 2200 lb. of this combustible material is required since 1 lb. of coal will not give more than from 1.7 to 2 lb. of steam, even with the latest constructions. This low output is due to the fact that the dry combustibles of the coal must uselessly evaporate its own moisture content, a feature which finds expression in the difference of the heating values of the raw coal and of the briquets made from it, the former containing only about 4900 B.t.u., while the latter possess 8100 B.t.u. per pound. Nevertheless, it is justifiable from the economic standpoint to employ wet lignite for steam raising in the briquetting process, since only the waste is used which cannot be utilized otherwise. When briquetting peat, this method would be uneconomical, since wet peat does not contain any waste, and therefore valuable combustible material which could be briquetted would have to be thrown away under the boilers.

The heating value of lignite briquets ranges from 7700 to 9600 B.t.u. per pound. The heat density of briquets in the size made in Germany is such that about 6000 lb. can be stored in a space of 100 cu. ft. While the price of raw lignite varies from \$1.75 per pound (Bohemian of 9900 B.t.u. per pound delivered at Leipsig) to \$4.30 (Bruex of 9900 B.t.u. delivered at Munich), the price of lignite briquets varies according to the location from \$1.98 per ton delivered at Cologne to \$4 delivered at Hamburg. When gasified in the ordinary single-bottom zone producer the gas generated from the raw lignite is high in hydrocarbons and produces an intense heat. Its composition is:

CO_2	6.4%
C_2H_4	0.7%
O	0.8%
CO	22.0%
H	9.6%
CH_4	1.6%
N	58.9%

It contains a series of distillates, such as paraffin, tar oil, creosote, asphalt, which are driven off in the upper layers from the fresh fuel charged through the hopper. These products are kept suspended in the form of a vapor, and are mixed with the producer gas proper. While, when specially utilized, these constituents make valuable by-products, they are worthless, undesirable, and directly harmful when the gas is to be used for power purposes alone, on a small scale. Since, on the one hand, they are mixed with water to such an extent that a transportation to chemical factories would not pay, on the other hand these by-products separate out from the gas when the latter is being cooled for engine use, and thereby obstruct pipes, pumps, and valves of the engine, and necessitate expensive and cumbersome cleaning apparatus and additional manual labor. Even then the degree of purification attained is not sufficient to guarantee continuous and reliable operation. Therefore, the only successful method of eliminating the tar is to burn it, preferably in the producer proper. Hereby the operating difficulties are at once overcome, and the gas is enriched accordingly. Systems which do not embody provisions to that effect can no longer be regarded as up-to-date. For large scale operations the recovery of by-products is a matter to be considered separately in each locality.

PEAT

Peat represents the first stage in the natural process of coal formation of which anthracite is the last. There are very large areas of peat land available all over the world. Germany alone has an area of 11,000 square miles. Ireland's area is one-tenth peat, and some of the Irish bogs are 50 ft. deep. A square kilometer of bog 4 m. deep will yield 700,000 tons of dried peat, including what must be burned in the preparation. In any case, there is a vast store of peat if it can be obtained dry. The empirical formula of peat is: $6C_6H_{10}O_5$ before decomposition. As this vegetable matter carbonizes it produces: $7CO_2+3CH_4+14H_2O+C_{26}H_{20}O_2$, the latter being the peat. Approximately, of the combustible matter in peat $\frac{10}{11}$ is carbon and $\frac{1}{11}$ hydrogen, but part of the latter is neutralized by the oxygen. There is no sulphur, so that peat is capable of producing an ideal metallurgical fuel.

The manufacture of peat briquets has not, so far, met with the same success as that of briquets from lignite. The main

reason lies in the fact that while raw lignite contains from 50 to 60 per cent. of water, which has to be evaporated by its dry contents, peat contains from 80 to 90 per cent. of water.

Therefore, to produce 1 ton of briquettable coal there must be evaporated from peat, containing 90 per cent. of water, 19,800 lb. of moisture, and from lignite containing 60 per cent. of water, 3300 lb. of moisture.

Among the means of drying peat may be mentioned first the air-drying process, which cannot be depended on, or, at least, is inefficient in unstable climates. Second, the mechanical process, which employs centrifugal and pressing machinery and filters, but requires a large capital outlay, and consumes considerable power. With this method, when combined with air drying, it is possible to reduce the water content down to 25 per cent. Third, the electrical process based on the phenomenon that the electric current drives the water without decomposition to the negative pole, while the peat cake settles on the positive electrode. To extract 35 cu. ft. of water from the raw material, an expenditure of from 13 to 15 kw. is required. With direct current of 1000 amperes it is possible to produce peat containing 40 per cent. dry matter and 60 per cent. water.

A new method of drying peat by electricity was invented by Graf Schwerin and has found extensive adoption in German practice. The process is based on the physical phenomenon known by the name of endosmose, which shows the characteristic feature that a liquid which is traversed by an electric current has the tendency to emerge through a porous partition wall. In the particular process employed by Schwerin peat is thrown on a wire screen and covered with a lead plate. When the electric current is sent through the peat the water which has remained there after compressing will drop out. A steam engine which uses this dried peat as fuel drives a generator, which, in turn, gives the current that is required for drying purposes. The steam engine consumes only one-fifth of the quantity of peat produced for the operation of the process.

A fourth method consists in the employment of closed ovens or retorts wherein peat is carbonized by the heat of the gases driven off, and the waste heat furnishes the means of drying off the material. This is called the Ziegler process, giving from

3 tons of air-dried peat 1 ton of peat coal, or coke, which serves as a substitute for charcoal and costs $10 per ton. From a ton of peat there are obtained 760 lb. of coke, 88 of tar, 12 of alcohol, 8 of ammonia sulphate, 12 of acetate of lime, the lime and the sulphuric being added components. This idea of producing products more valuable than peat and of smaller weight per unit value appears sound. In practice, the availability of suitable peat of low ash contents, the cost of by-product recovery and the salability of the by-products will determine the commercial economy of the process to a large extent.

It may be mentioned that in the process of dry-peat production from the raw material gas engines cannot be used to advantage, as in this case not the thermal efficiency of the gas plant, but the complete commercial-economy coefficient, must be considered. The all-round economy of a steam plant for this kind of work is greater than that of a gas plant, as the steam engine with from 12 to 16 per cent. thermal efficiency gives off the total amount of exhaust steam containing 75 per cent. of the heat introduced, while the gas engine only gives out the sensible heat of the exhaust gases, that is, about 20 per cent. for the purpose of drying, leaving aside the amount of steam which can be generated from the sensible heat of the producer from the overflowing gases and from the engine jacket water.

The best practice, if the local conditions favor the distribution of electric current to the neighboring districts, is naturally to produce gas from peat and employ it in gas-engine-driven dynamos for the generation of electric power, and to recover and sell the by-products.

With regard to the price of peat coal, it is claimed that the fuel may be produced at $1.90 per ton. The Ziegler process costs more, but this is in some localities equalized by the value of the costly by-products.

One man with a digger will dig five tons of raw peat, equal to half a ton of dry fuel, in an eight-hour day. A dredger 110 ft. long would gather in the neighborhood of 300 tons of dry peat a day with, perhaps, three men as a crew, thus reducing labor charges to a very low point.

The economic attainments of peat in producer work will be discussed later.

Generally speaking, peat offers the same advantages for gasi-

fication as does lignite, provided that the contents of moisture can be reduced to a similar extent.

If peat cakes are to be used for power purposes on a small scale, the extraction of the tar is best performed by burning it in a second incandescent zone in the producer proper, whereby the gas is enriched in proportion to the heat contents of the tar. This method has given as excellent results, in producers of modern construction, as have been attained with lignite. The rational utilization of peat on a large scale requires the recovery of by-products, especially of ammonium sulphate.

BRIQUETTING FOR PRODUCERS

A few words may be said on the important question of briquetting raw fuels for use in producers. It was mentioned before that peat should preferably be used in raw form whenever possible, since briquetting does not pay, if the briquets are to be transported over large distances. Their low heat density, that is, the thermal value per unit space, precludes their commercial distribution over wide territories, especially in a country like the United States.

In Germany the railways are owned by the government and are run with a view to aiding the development of industries rather than securing the maximum immediate profits from their operation. River and canal traffic are also more in vogue, and in cases where the tariff rates imposed by the government on the transportation of raw materials are too high, as in the iron industry, there several concerns will unite into a syndicate and build their own electric railway or traction system so as to get control of the transportation factor, similar to what obtains in the United States Steel Corporation. So the trouble that confronts the briquetting industry in Germany is not so much that of transportation, at least not so far as lignite is concerned, but is offered by the fact that lignite briquets are being more and more used for domestic purposes, and that the larger sizes there employed can be manufactured with greater profit than can the smaller sizes which must be used in producer work in order to secure regularity of operation. On the other hand, the price which is paid for the smaller briquets in industrial pursuits is usually lower than what can be obtained from the sale of larger

briquets for domestic uses. Therefore the inducement to manufacture producer briquets in the "industrial" sizes is not very great and there is danger that the supply may not, in some not distant time in the future, keep up with the rising demand.

Summarizing, it may be said that the event of the gasification of coal in producers has brought about a marked tendency for specialization in methods of power generation. There is for every locality a certain fuel, and for every fuel a certain producer, and for every producer a certain application, and it is only by a judicious combination of the three factors that maximum industrial economy of operation can be secured.

TRANSVALUATION OF BY-PRODUCT VALUES

The generation of gas in blast furnaces and coke ovens, which represent the first stage of producer development, is a secondary or by-process accompanying the respective main operations of smelting the iron and of making coke by the destructive distillation of coal in retorts. It is interesting to observe how in the course of time the valuation of these by-product gases has gradually increased. In the iron industry blast-furnace gases have become the potential source of energy for driving all machinery required within the works to carry out the entire series of converting and finishing processes which transform the original ore into marketable steel products. When rightly used and husbanded they may even serve, in large-scale operations, for delivering power to outside consumers, provided that the latter are located within the commercial-distribution radius of the central works. In the coke-making industries where the power factor within the plant is an insignificant amount, coke-oven gases, generated in modern by-product ovens, are now distributed to neighboring districts either for heating, lighting, or power purposes, and have thus become formidable competitors to the ordinary illuminating-gas supply undertakings, which they will eventually wipe out. Together with the revenues obtained from other by-products which are gained through the process of purification, the sale of coke-oven gases has become a principal source of income to the management of modern European and American works.

Gas Producers for Lignite, Peat, Bituminous Coal, Culm, etc.

With the growing appreciation of the value and importance of gaseous by-products in the iron and coal industries, the idea has gradually forced itself upon the engineer and economist that the gasification of raw coal in producers and the utilization of the gases subsequent to their liberation for industrial purposes and the recovery of by-products is a more all-round efficient mode of operation than is the direct burning of coal in furnaces or under steam boilers. Gas producers have found almost universal adoption in metallurgical, ceramic, cement and other pursuits, and wherever a clean, regulable gas fire is preferred for heating and smelting. The possibility of smoke prevention, of long-distance transportation of the gas, and last, but not least, the possibility of employing inferior grades of coal in the combustion process, have largely aided to their rapid and general introduction. Even steam power is taking recourse to the gas-producer furnace as the last remedy to keep pace with the ever-growing mode of generating power in gas engines directly, and without the intervention of inefficient and passive machine parts, such as constitute the boiler equipment.

It is a well demonstrated fact that gas firing, generally speaking, is more advantageous than grate firing. Yet the gas generated in modern producers contains theoretically up to 90 per cent., but practically only from 70 to 75 per cent. of the heat which is liberated through the direct combustion of coal, the rest being lost through radiation in the producer and through cooling in the overflow ducts and transmission pipes. The superiority of gas firing is founded, among other things, on the circumstance that, with a surplus of air of only 20 or 30 per cent. over what is theoretically needed, it is possible to attain complete and smokeless combustion, while with direct grate firing the surplus of air must amount to from 100 to 250 per cent. in order to obtain the same good results. By far the greatest part of the heat which is liberated through the combustion process is lost on account of the high temperatures at which the burned products are permitted to leave the flues. Therefore, the larger the quantity of products of combustion per unit fuel the less efficient will be the utilization of the fuel. Another advantage of gas firing

is that the waste heat can be used in a most simple and efficient manner for preheating gas, as well as air, and even the fuel before combustion; moreover, the capability of regulation is greater and the temperatures obtained can be kept more nearly even than is possible with grate firing, thereby securing greater regularity of product.

Gas producers, whether used for heating or for power purposes, have therefore effected several tangible advantages over the traditional methods of power generation. It should be remembered, however, that by far the most far-reaching of all is the possibility presented to employ, for gasification in producers, low-grade fuels such as hitherto escaped utilization entirely. The promoting effect which this remarkable achievement will ultimately have on the development and distribution of iron production, and on the development of all industries which were formerly restricted through the necessity of employing high-grade coals and through the unreliability of transportation conditions to certain narrow localities, can be imagined, though it is impossible to realize the ensuing results to their fullest measure.

What the writer submits in the following is a critical discussion of those types of gas producers which have given satisfactory results in several years of continuous service, in Germany, operating on lignitic and peat fuels, mine culm, etc. To avoid misapprehensions, it should be said that while lignite, peat, and culm are materials whose characteristics, though widely varying with geographical location, are similar as concerns gasification in producers almost all over the world, this is not the case with the great mass of ordinary bituminous coals. Thus there are not in Europe bituminous coals which resemble closely the bad caking variety which abounds in this country. So it must not be imagined that bituminous coal producers which give satisfactory service with English or German coal will behave likewise with American. Many a firm laboring under that impression has had to pay for it very heavily. As was said, conditions are different with lignite and peat fuels, especially when they can be brought to a similar degree of moisture contents, or still better, when they are briquetted. As a matter of fact no more universally suitable fuel than brown-coal briquets is available for producer work, provided that they can be obtained in the smaller sizes.

In order to understand the course of producer development, it

must be remembered that tar, which is a by-product of the destructive distillation of coal in retorts, is a very undesirable element — for reasons that may be easily defined — if the gas is to be used for driving internal-combustion engines. When the tarry vapors that are suspended in the gas are extracted by special separators outside the producer, then this separation represents a loss of from 4 to 10 per cent., depending, of course, on the grade of coal used. If the tar is destroyed by superheating within the producer, then the water vapor is decomposed together with the tar-forming hydrocarbons, so that the gain is a double one.

CONSTRUCTION OF LIGNITE-PEAT PRODUCERS

Turning now to the constructive principles of lignite-peat producers, it may be said that both fuels can be used in the same type of producer, but that the depth of the combustion zones must be properly adjusted to suit conditions. I shall omit discussing in detail the various earlier systems existing on the Continent, all of which have the common principle of generating the gas in one producer and passing it through a second column of incandescent fuel, thereby burning up the tarry vapors or transforming them into stable gases. They all have this disadvantage, that two producers are necessary to do the work of one, and that manual or automatic labor is required to perform the work of switching the valves.

The next step in producer evolution reveals a general tendency first to transform the coal into coke and to gasify it afterward. The gases distilling from such process tend to form tarry products; therefore, the natural solution presents itself to guide these vapors through another incandescent zone, which is located not outside, but in the producer proper. Among the construction of this class may be mentioned those of Boutillier and of Crossley Brothers, the details of which can be found in any of the handbooks on gas producers. Quite a number of makes show a very high column or zone of combustion, the gas being drawn off in the middle of the hight. The coal which lies above the discharge duct is coked and the distilling gases forced, either by steam jet or blower, through a special pipe either below or above the grate, so that in order to get to the main outlet they must first pass through the incandescent zone resting on the

grate. If the distilling vapors containing the greater part of the tarry products are discharged below the grate, they will mostly be burned up, though there is no appreciable loss of heat involved in the process. The carbon dioxide produced is reduced to CO when passing through the incandescent zone, while the steam developed is split again into its components. When the distilling gases are made to enter above the grate, they cannot find the

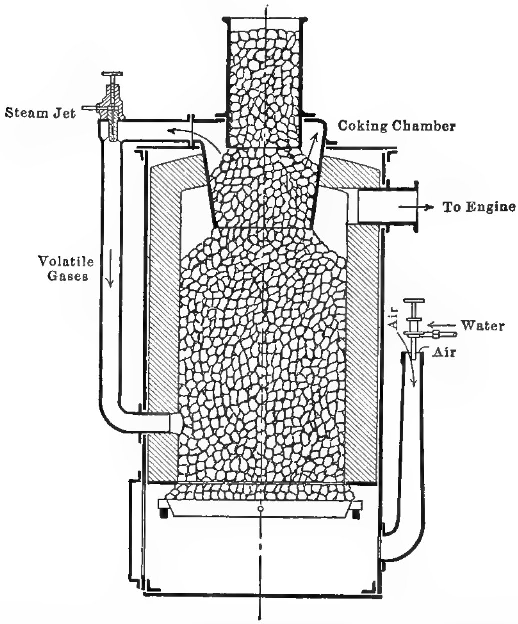


FIG. 154. — Bituminous Coal Producer (Fielding), Working with Tar Destruction. The Volatile Gases formed in the Coking Chamber are forced through the Incandescent Zone above the Grate, where they are Split up into Stable Compounds.

oxygen necessary for combustion and are therefore split up or transformed into permanent gases.

Among the more remarkable producers of this class may be mentioned the Daniels bituminous coal producer, built by the Light Pill Iron Works, Stroud, Gloucestershire, the producer of the Société Francaise de Construction Mecanique in Paris, the Porter producer, the Fielding producer, and the Pintsch producer. The Fielding producer is shown in Fig. 154.

All these constructions have the disadvantage that they

require means separate from the producer for generating steam or artificial draft to convey the volatile gases under or above the grate; it is also difficult to so adjust the respective action of the engine, sucking gas from the one side, and of the fan or jet aspirating or pressing from the other, that the antagonistic flows proceed without mutual interference.

THE DOUBLE-ZONE PRODUCER

The latest and most successful step in producer development, and the one deserving our most careful consideration, is that presented in the double-combustion producer, having two zones of combustion, of which one is located at or near the top of the fuel charge, and the other above the grate as usual. This construction has evolved from a natural combination of two well-known types, the ordinary and the inverted producer, the latter drawing in the air at the top and discharging at the bottom, while in the double-zone producer, air is drawn in both ways, from top and bottom, the gas being taken off midway between the two spheres of combustion. This combination has been adopted by several concerns both in Germany and France, where the greatest headway has been made in this field of gas-power application. Of the more remarkable constructions may be mentioned the Lecauschez producer, consisting of three conical chambers, arranged one above the other. The top space serves for storage; the middle one contains the fuel which is burning in the upper or outer layers that are exposed to the influx of the air. The lower chamber contains the fuel which has gradually descended after being coked in the upper part of the producer and is thoroughly burned by the air entering through the grate just as in the ordinary suction coke producer. The distilling vapors produced by the coke and coal at the top are drawn through the upper and incandescent zone, whereby the greater part of the tarry constituents and heavy hydrocarbons is burned. After passing this zone, the upper (Siemens gases) are mixed with the Dowson gases ascending from below, and which are produced in the usual way with a mixture of steam taking part in the process. By mixing the gas from above with the hot gases from below, the tarry particles, which may have passed through the incandescent zone without being consumed, are now superheated and trans-

formed into stable or permanent gases which will not condense after leaving the producer proper. This producer has been successfully tried with catalonic lignite, a fuel of which 1 ton will give out 130 lb. of tar; it has only from 7 to 10 per cent. of ashes, and about 40 per cent. of volatile matter, of which 10 per cent. is water.

Another producer of this class is the one built by Fichet & Heurty in Paris, and which shows the same general characteristics, but is more complicated and expensive to build.

THE KÖRTING PRODUCER

The firm of Körting Brothers, Körtingsdorf near Hanover, has recently perfected a producer having two zones of combustion

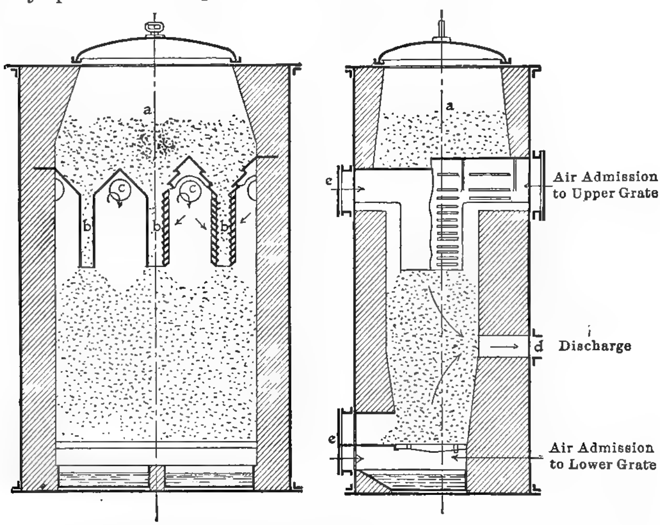


FIG. 155. — Körting Double-Zone Producer for Raw Air Dried Lignite and Peat. The Volatile Gases are Burned in the Upper Incandescent Zone which is Supported by a Second Grate.

and two grates, one at the bottom, horizontal, as in all other cases; the one above is intended to prevent the upper zone from sinking down — which a fuel with high moisture contents is apt to do — and consists of several vertical grates, which form thin pockets, serving to coke the fuel fed from above and to guide the distilling gases through the column of gasified fuel to the discharge duct. The Körting producer is shown in Fig. 155. One advantage

common to all double-zone producers is that, on account of the double combustion, no fuel or carbon is discharged through the grate unburned, together with the ashes; while this is often the case with the ordinary, and especially with the inverted producer. To avoid such leakage, a very deep bed of ashes must be carried, which offers in the common type of producer great resistance to the air passing through it. The combustion in the new system is so perfect and the ashes so well burned that no revolving grates or other means for discharging them are required. This type of Körting producer is especially well adapted for burning peat cakes with up to 20 per cent. moisture.

THE DEUTZ DOUBLE-COMBUSTION PRODUCER

One of the simplest of all these constructions is the Deutz double-combustion producer, which is equally applicable for lignite and peat, preferably in form of briquets.

The first attempt to gasify raw lignite and peat in producers was made as early as 1902 in Deutz and the system used was the ordinary pressure type. In these earlier gas producers the principal effort made was to provide for the removal of the slag and cinder, such methods as the provision of an iron, water-cooled hearth, to which the slag would not adhere, or a totally removable hearth, mounted on a wheeled truck, being employed. These arrangements made no provision for the gasification of the tar, etc., but involved the employment of subsequent operations of condensation, scrubbing and purifying. Such producers have been made and operated successfully by the Deutz-Otto gas-engine works, and tests by Professor Meyer, using Lausitz brown coal, containing 29 per cent. of carbon and 58 per cent. of moisture, showed a gas of 1272 calories per cubic meter, or 143 B.t.u. per cubic foot. The fuel consumption was from 1.5 to 1.6 kg. per horse-power, which is excellent when it is considered that the lignite itself had a calorific value of only 2190 calories per kilogram, or about 4000 B.t.u. per pound; the power cost working out only about 0.6 pfennig (0.14 cent) per horse-power per hour. Several of the early plants are still in active service, operating on raw peat with 50 per cent. water contents. However, pressure plants have now been universally abandoned in Germany, and they should not be adopted in this country. They are less safe, occupy greater floor

space, and are more expensive in first and operating cost. The separate steam boiler and the gas holder are both apparatus which can be dispensed with by superior measures. The advantages realized by inserting between the producer and engine a fan whose output is automatically varied according to the plant load, thereby making the system more flexible and effective and the producer independent of the pulsations of the engine piston, are known. Even for heating purposes this arrangement is preferably used.

Therefore, all of the latest and largest installations are suction

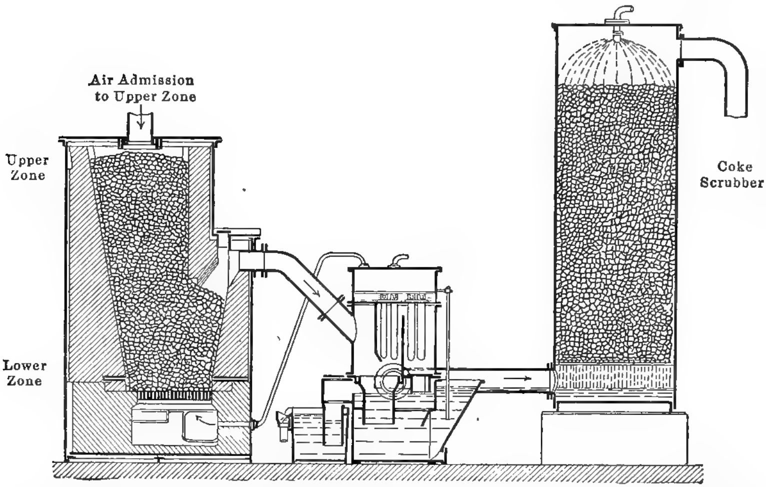


FIG. 156. — Deutz Double-Zone Producer for Lignite and Peat Briquets, Showing Economizer for Preheating the Air and Raising Steam, Dust Catcher and Coke Scrubber for Cleaning and Cooling the Gas.

plants, running up to 1000 h.p. per unit. Another reason why the successful pressure plants were abandoned is that the water emerging from scrubbers, washers, and tar separators is very dirty, difficult to dispose of, and contains poisonous substances, which are apt to destroy animal life in the rivers or lakes wherein they are discharged.

The latest type of Deutz double-zone suction producer, which is shown in Figs. 156 and 157, has been running successfully for some time, and has within very few years already reached the imposing figure of 40 installations, aggregating a total capacity of about 7000 horse-power.

The producer consists of a vertical shaft of rectangular section

with rounded corners, which is closed at the bottom by a fixed grate. The top of the furnace is covered by a sliding hood running on rollers and having an opening for the admission of air. When feeding coal, this cover has to be pushed aside, but there is no danger of any gas escaping, as the air is continuously drawn through the grate below and through the admission pipe above. The operation of feeding has to be performed once or twice in an

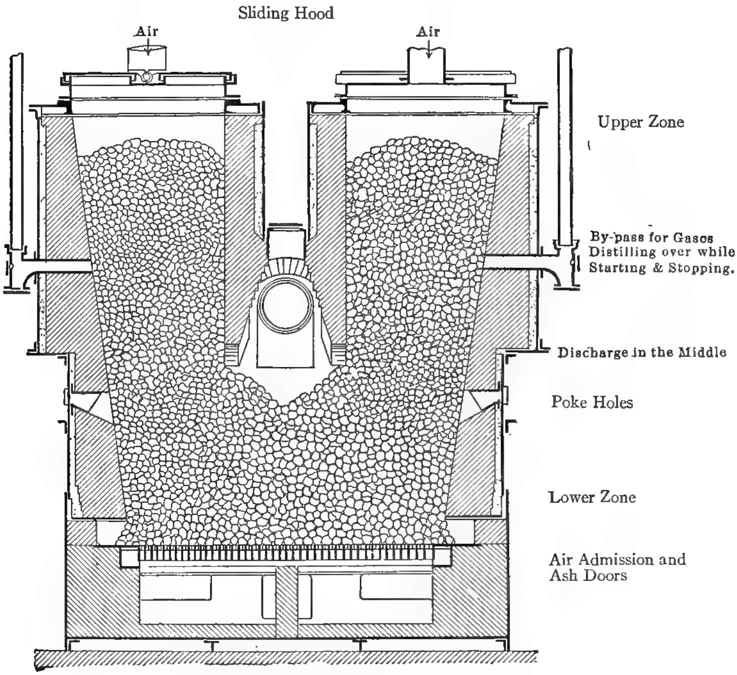


FIG. 157. — Deutz Double-Zone Producer for Large Work. Raw Lignite and Peat, Containing up to 25 per cent. of Water, and Briquets can be used as Fuel.

hour, unless it is automatic. The gas escapes through an opening in the generator wall, which is located slightly below the middle of the producer shaft. There are several poke-holes provided at the sides and at the bottom end, while the interior of the producer can be thoroughly inspected and poked from the top without appreciably interfering with the working process proper. Similarly the grate may be cleaned or inspected through doors provided above and below it.

The working process is the same as described before, and extremely simple. The coal is coked in the upper layers, and partly burned, so that a zone of incandescent fuel is formed. The distilling gases are drawn through this zone, whereby the tarry vapors are either burned or transformed into stable gases. This process of permeation is continued when the gas passes through the lower layers, consisting of coke or rather of coal which has been distilled, until they meet and mix with the gases ascending from below which have been generated by the air passing through the incandescent layers of coke resting on the grate. By the mixing of the gases the rest of the unstable compounds are superheated and made permanent. The process is so effective that the means of cleaning consists only of one coke scrubber provided with a water spray. Between producer and scrubber, the water seal is inserted, having a splash overflow, which serves to absorb the dust that is drawn off with the gases. A fan is arranged behind the scrubber which serves for starting purposes, or it is run continuously if higher engine output is desired. A three-way valve is inserted at the branch between scrubber and engine, in order to be able to blow off the gases into the chimney when stopping and starting.

Ordinary raw lignite contains so much water that no steam need be added. It is sufficient to have some water in the ash pit under the grate, in order to prevent the fine ash dust from mixing with the gases.

TESTS OF THE DEUTZ PRODUCER

An endurance test made with this producer and lasting 321 hours gave the following results: The fuel used was lignite briquets, having a calorific value of 8490 B.t.u. per pound, and containing 35 per cent. fixed carbon, 45.3 per cent. volatile matter, 4.8 per cent. ash, and 14.9 per cent. water. The consumption per brake horse-power-hour including all losses was found to be 1.46 lb. The vacuum averaged 3.5 in.; the gas was examined several times and showed some dust, but almost no tar. Clinkers were removed every six hours. This operation had no influence on the quiet running of the engines. The water was easily cleaned of the dust which is carried off by the gases. The resistance of the washer remained below 2 in. of water, and showed no appreciable influence on the output of the engine.

The load was kept constantly at 81.3 h.p., while the revolutions averaged 180.5 per minute. When inspecting the engine, it was found that the plant could have been run much longer without requiring any cleaning. In continuous operation it is possible to get even better results than here recorded, as the producer remains in the condition of stability, and gives a purer gas than when disturbed by shutting down.

Another test was made with raw lignite from Bruex, having a calorific value of 9190 B.t.u. per pound, and containing 22.45 per cent. of water, and 4.38 per cent. of ash, and costing $2.25 per ton delivered. The engine was run at an average load of 66 h.p. and at 144 r.p.m. The consumption was found to be 1.19 lb. per brake horse-power-hour. At a load of 100 h.p. and 180 r.p.m., the consumption was 1.10 lb. per brake horse-power-hour. The fuel cost per brake horse-power-hour is, therefore, 0.12 and 0.11 cent, respectively.

A third test made on a plant of 300 h.p., with lignite briquets, having a heat value of 9170 B.t.u. per pound, and containing 13 per cent. of ash, gave the consumption per brake horse-power-hour of 1.15 lb. Fig. 6 gives the graphic representation of the performance of the Deutz producer.

The best result known to the author that has been so far obtained on the continent with a modern steam plant (compound locomobile with superheat), and working with the same fuel and under the same capacity and load conditions, is 2.46 lb. per brake horse-power-hour, which is more than double the amount consumed in the gas plant.

That much to the efficiencies that have been realized. Now to the operative conditions and difficulties.

OPERATING CONDITIONS AND DIFFICULTIES

The temperature of the incandescent reducing zone, the closeness of contact between the tarry vapors and the incandescent material, and the duration of contact exercise an appreciable influence on the effectiveness of tar destruction. These three factors are in turn dependent on the special characteristics of the fuel used, further, on the conditions of operations, and before all on the rate of gasification or speed of driving. If the fuel is of the kind that is apt to stick to the walls, or if it forms arches

or big lumps, or if it cracks, leaving open wide fissures or gaps through which the gas can escape unobstructedly, then an intimate contact between the volatile gas and the reducing fuel is not possible. If the engine runs for a considerable time at a light load, the temperature of the reducing zone will go down. If, on the other hand, the load is a heavy one, then the rate of gasification is very rapid and the speed of gas flow is very high. Consequently, the time available for the incandescent zone to act on the tarry vapors is insufficient. To secure good results the rate of gasification should be kept as nearly constant as possible. This can be done, besides by other means, through by-passing at the lower loads the gas drawn off by the fan back into the producer, where it is consumed again.

A fluctuating moisture content of the fuel influences the temperature of the decomposition zone. Load variations are apt to shift that zone either higher up in the fuel column when the suction effect is weak, or lower down when the engine or fan is drawing hard. The chances of decomposition are changed accordingly. A similar effect is traceable to sudden drops or changes of location of the fuel material, such as are produced either by poking from above, or by drawing ashes irregularly below, or by other manipulations.

The decomposition of the tar is, therefore, dependent on many variable factors which must be considered and met in order to secure good results. Of course, the proper design of the producer has a great deal to do with this question, but it cannot be denied that at low loads the tar destruction is less effective than it is at the higher ranges, even if the same kind of fuel is used throughout the run. Usually either the lower or the upper air admission are adjustable so as to be able to regulate the rate of draft.

Lignite and peat briquets are the most desirable fuels to use in the double-zone process, on account of the regularity of form and composition. The employment, in this type of producer, of raw fuels containing a great deal of water requires skilled attendance, which is more difficult and costly to procure in this country than it is abroad. When using raw fuels of the lignite and peat class it is advisable to insert in the shaft a second grate for resting the upper layers of the charge and enabling the formation of an incandescent zone, since otherwise the charge will sink down too suddenly.

One plant in Meuselwitz, Germany, is working successfully with raw lignite containing 40 per cent. of water. Peat is equally applicable and has been burned successfully with a water contents of 20 per cent. Ordinary bituminous coal, which does not cake excessively, may also be used, though, of course, the usual means for generating steam have to be added. As was said, low-grade bituminous coal has not given complete satisfaction. The trouble is that in the upper zone of gasification such fuel is apt to cake and form big solid lumps which have to be destroyed by poking. But the difficulties in gasifying fuels of powderous and granular composition have been successfully overcome in producers of the Pintsch and other types. There are plants of100-h.p. units working satisfactorily in Insterburg, where the fuel which settles down in the smoke box of locomotives is utilized, consisting of grains of from 0 to 7 mm. size and containing from 15 to 20 per cent. of ash.

UTILIZATION OF GARBAGE AND WASTE

Similarly, the gasification of city garbage and sewage has been successfully carried out, and plants of this kind are working in Köpenik, near Berlin, and in Dresden. The method consists in admixing with the garbage and sewage in the city pipes a small percentage of powdered lignite, which absorbs the humus particles of the waste, and certain ferro-aluminum and magnesia salts to destroy such molecules as resist absorption. The solid part of the mixture is then allowed to settle down in ponds, is dried afterward and burned in the producer. With this method, we can generate 1 brake horse-power-hour from 4.4 lb. of garbage and sewage. A city of 50,000 inhabitants produces daily about 25,000 lb. of waste products, from which can be generated 6000 horse-power-hours or 1,460,000 kilowatt-hours a year.

For inferior grades of bituminous coal, as well as for slack fuel, residues and refuse, such as is found in coal mines and iron-smelting plants, the above system is not recommended.

PRODUCERS FOR BITUMINOUS COAL, CULM, ETC.

The Jahns Process.—For transforming the lowest grades of fuel, the Jahns process is one of the few which has met with complete

success. It is based on the same principle that has been in use for a number of years, namely, to draw the gases distilling in one producer through an incandescent charge of fuel contained in another. The novelty of the Jahns process is of a purely mechanical nature and consists in the combination of four single ovens in one unit, and of several units in one group, similar to what is done in the brick furnaces of the ceramic industry. The single furnaces are charged simultaneously and at certain intervals, and the charges are burned without reloading. Hereafter the producers are shut down, one after the other, are emptied, cleaned, and re-charged and started up again, thus forming a continuous process of gasification. The single ovens are suitably connected through channels in a succession, corresponding to the time of starting, and in such a way that the tarry vapors coming from the two younger producers are conducted by means of a common suction device through the older producers, that is, the one wherein the charge has been almost completely burned and which is therefore in a state of thorough incandescence and high temperature. The air in this producer necessary for keeping up combustion is drawn in together with the water vapor and steam from below the grate, where it mixes with the gases generated in the other producers. At the time when the fourth producer of the ring is started, the first or oldest has reached its maximum temperature, the upper layers of its charge having been coked both by the radiating heat from the lower zones, as well as from the adjoining producers, and from the gases constantly passing through. Thus it can generate, from its own charge, only gases which are entirely free from tarry products.

After this fourth producer has served its purpose, namely, to act as a tar separator and destructor for all gases generated in the three other retorts, it is usually shut down, provided that its charge has been completely burned out. If not, it is connected by a valve and duct to the third generator, which has now attained its highest temperature and power of decomposition and takes the place of No. 4 as by-pass oven for the gases from Nos. 1, 2, and 4.

When the oldest producer is quite exhausted, it is shut down, separated from the rest, cleaned, freed from clinker, charged anew and started up again, the incandescent ashes of the ash pit and the hot walls of the generator being sufficient means to insure the immediate beginning of energetic combustion. The refuse

left in the producer and which is discharged during the shutting-down period that requires from one-quarter to three-quarters of an hour, occupies one-quarter of the volume of the coal charged, or, when mine culm is burned, the refuse left constitutes three-quarters of the charge volume.

As all producers are in closed connection, the exchange of active producers and the shutting down of the exhausted ones are performed without any interruption or influence on the gas making.

The larger the number of single producer units which are connected to a ring and burn all at the same time, the smaller, of course, is that part of the charge which has been freed from tar and enters the process of advanced gasification. The longer also this part will be exposed to the influx of heat. Therefore, the decomposition of the tarry constituents and the coking of the upper layers of the charge will be made more perfect, and the gases generated will be absolutely free from tar.

The accompanying drawings, Figs. 158 and 159, show the Jahns producer as built on the Von der Heydt coal mines. Each unit of a set of four single producers forming a group or ring is interconnected through a round central channel or duct, and ports laid in the brickwork, where the four inner walls of the producers intersect.

This vertical channel c has ports p above and below, connecting it with each individual retort or combustion chamber by means of valves v_1 and v_2 which are operated from the charging floor. The producers have rectangular section with rounded corners and are lined with firebrick within and surrounded with a sheet-iron mantle without, while some insulating material is inserted between to prevent heat loss and diffusion of gases through the walls. The charging doors d at the top of each shaft are provided with hoods, which all discharge into a common gas main and which can be closed by individual gate valves. The main is connected to an exhausting fan, which aspirates the gases through producers, scrubbers, and washers, and presses them into a gas holder, which is large enough to equalize load fluctuations of smaller range. The bottom grate is of the fixed type but can be removed, so that the ashes may fall into the ash pit unobstructedly. Of course there are doors provided in the usual manner for the removal of ashes.

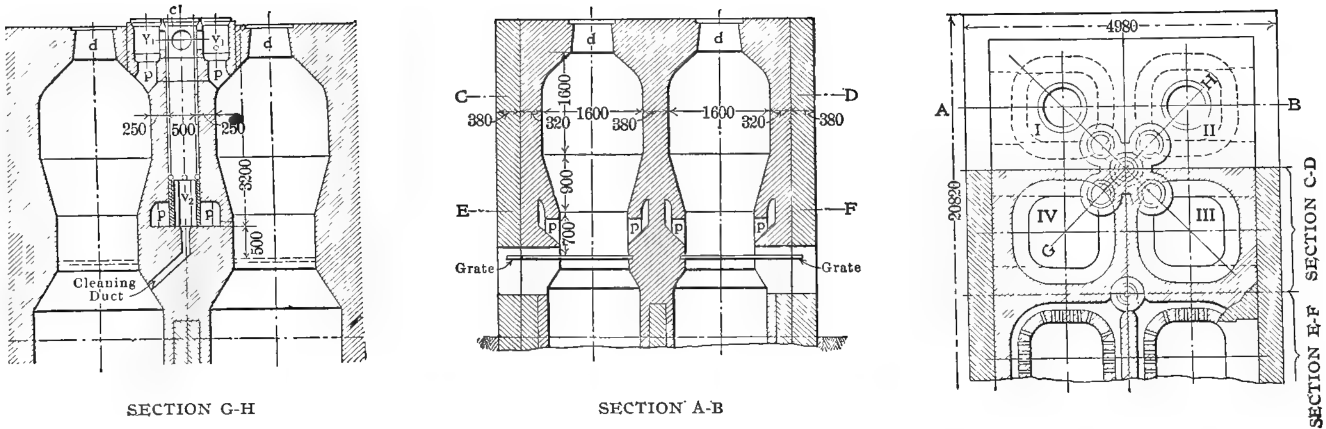


FIG. 158. — Construction Details of Jahns Ring Producer.

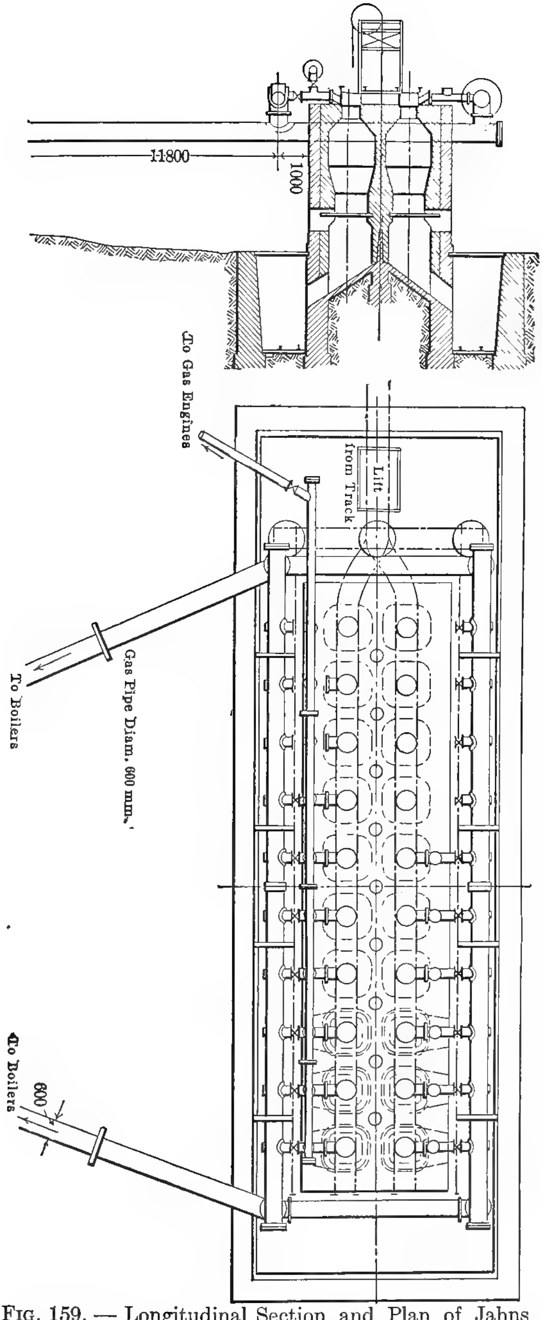


Fig. 159. — Longitudinal Section and Plan of Jahns Ring Producer, Gasifying Mine Culm, a Material Containing 25 per cent. Combustibles and 65 per cent. Ash (Efficiency 80 per cent.).

To illustrate the working process more in detail, it may be said that producer 1 is charged while the ports connecting with the central channel are closed and the gate valve for the gas outlet at the top is open. The culm is dumped through the charging doors from cars running on a track laid on top of the bank of producers.

When producer 1 is started for the first time from cold, the charge is ignited in the ordinary manner by wood kindling. When a quarter of the time which is necessary to consume the charge in No. 1 has elapsed, producer 2 is started after its ash doors and upper ports connecting with the central channel, as well as the lower ports connecting said central channel with producer 1, have been opened. The gases generated in No. 2 now pass through the vertical channel, entering above and leaving below, and through producer 1, entering through the bottom ports and leaving through the hood on top, and flowing to the common discharge main, together with the gases generated in producer 1.

Producer 3 is started the same way after No. 1 has completed half of its burning period, and No. 2 about a quarter. The cycle of operation is completed and regular working of the gas-making process secured, when producer 4 enters the series and is started, so that the gases of Nos. 4, 3, 2 all pass through the incandescent charge of No. 1, which has now attained its maximum temperature. Having completed about three-quarters of its total running time, producer 1 has above the zone of combustion proper a series of layers which are coked, and when burning will produce gases that are entirely free of tar or possess only a negligible quantity of it.

When the upper part of charge No. 1 is so far burned out or exhausted that the gases passing through it are no longer regenerated, then the upper discharge gate valve and the lower inlet slide valve of producer 2, as well as the upper outlet slide valve of producer 1, are opened, thus directing the flow of gases through the central channel into the producer 2, while the discharge gate valve and the bottom sliding valve of No. 1 are closed.

The gases of Nos. 1, 4, 3 now have all to pass through producer 2, where they mix with the gases of same, are regenerated and flow on to the common gas main. When producer 1 is completely burned out it is shut down by closing its upper valve, connecting with the central channel, thus separating it from the

other units of the ring, which proceed with the generation of gas without interruption. Hereafter the grate is drawn out, the ashes fall into the ash pit, and any clinkers that may have formed in the process of gasification are removed. After thoroughly cleaning the producer chamber, which process will require from one-quarter to three-quarters of an hour, according to the grade of coal used, the grate is pushed in again and a new charge dumped in from the charging floor. Gasification is provoked immediately by the radiant heat of the walls, and at such pressure that, as soon as valve *v* is opened, the gases generated in No. 1 at once enter the central channel and from there proceed through the lower ports into producer 2, together with the gases of Nos. 4 and 3.

It is seen that producer 2 simply replaces No. 1 as a regenerator for the gases generated in the other units of the ring, while later on No. 3 takes the place of No. 2, and No. 4 that of 3 in succession, until the whole cycle of operation is started over again.

The gas produced in the Jahns ring producer can be employed as well for heating as for power purposes, though, of course, for use in gas engines it must be subjected to a more thorough cleaning process than when fired under boilers or otherwise. One producer holds about four tons of coal or five tons of "mine culm." The burning time is 96 hours for coal and 48 hours for culm. The time interval between starting fire in the different ring units is 24 and 12 hours respectively, and the periods of gas making 36 or 24 hours, so that the gas periods of two producers are partly coincident. The progress of gasification is indicated on a try cock in such a way that, when the escaping gas ignites, the unit is coupled in series with the ring. Complete combustion of the charge is secured by letting each unit run for a considerable time after the gas-making period proper is over, at the same time blowing much steam through the grate. The ashes or refuse falling through the grate are still in a state of incandescence and are kept there, giving off their gas or vapor into the producer above.

In the course of practical operation it was found that, under certain conditions, the complete charging and emptying of the single producers was not advantageous, too much heat being lost. It was preferred to do the charging of new fuel and the

drawing out of ashes and slag gradually within shorter intervals, so as to be able to keep the fuel zone or column at any desired hight. Thus a wide margin is created for different kinds of fuels; also, the composition of the gas can be varied to suit conditions. When gasifying mine culm containing from 60 to 65 per cent. of ashes and having a heat value of about 2400 calories per kilogram (4320 B.t.u. per pound), a gas free of tar and of the following composition was obtained, in per cent. of volume: CO_2 12.6, CO 13.1, CH_4 0.9, H 27, O 0.57, heat value, low, 1183 calories per cubic meter (132.5 B.t.u. per cubic foot). Considering the very low grade caking coal used, this analysis certainly reveals an excellent performance of the Jahns producer. The high hydrogen contents accompanied by a high contents of carbon dioxide is due, partly to the burning of the tar and partly to the formation of slag, which with such low-grade fuels is a serious factor to contend with. If the slag tends to fuse low temperatures must be preserved in the producer, and this, of course, favors the formation of carbon dioxide.

According to the kind of fuel used it is necessary occasionally, every five or six hours, to agitate or settle the fuel bed by means of a stoking bar which is operated through a small observation hole in the charging door. This applies especially to very porous coals and those that cake excessively. The size of coal, the fusibility of the ash contained in the coal, and the tendency to clinker, will finally determine the rate of combustion and the amount of care required. As in all other producers the honeycombing of the fire must be prevented, lest its resistance become so great that an annular space is formed at the walls, which the blast will seek as the passage of least resistance, thereby making the gas inferior in calorific value by so much as its contents are enriched with carbonic acid. The efficiency of the producer was found on test to be 80 per cent.

A plant of this kind which has been in use since April, 1902, is located in the Von der Heydt coal mines. The fuel used is refuse which drops from the coal conveyers and tipples and was formerly wasted. The material contains only 20 per cent. of coal and is now fed directly to the producers. In this way 2100 tons of culm are gasified per month, giving a total of 3,716,000 calories (14,000,000 B.t.u.), or 1 kg. = 2.2 lb. generates 1800 calories (7140 B.t.u.). The cost of 1000 calories is 0.86 pfennig or 1000

B.t.u. = 0.005 cent. Of the heat developed, 13,650,000 B.t.u. are used to generate 3500 tons of steam. One ton of steam from gas-fired boilers costs, therefore, 0.20 cent against 0.44 cent from coal-fired boilers. Part of the gas is used in gas engines for the generation of electric power. The gas cost per 1 brake horse-power-hour, assuming a consumption of 2500 calories (9750 B.t.u.), comes out as 0.05 cent. The cost of steam per 1 brake horse-power-hour in steam engines is found to be 0.51 cent when steam is raised in coal-fired boilers and 0.24 cent when it is raised in gas-fired boilers. In this particular plant, the gases are drawn off from the hottest retort by means of a steam ejector, leaving at a temperature of about 650 deg. C., and are pressed through a scrubber and sawdust purifier into a gas holder having 150 cu. m., equal 5295 cu. ft., contents. The average composition of the gas is from 7 to 9 per cent. CO_2, 16 to 20 per cent. CO, 18 to 22 per cent. H, and 1 to 4 per cent. CH_4. The heat of combustion of the gas in the combustion chamber of the engine varies between 1000 and 1500 deg. C. The gas generated in the ring producer burns without smoke or soot and without leaving any residues. It is therefore equally applicable for heat and power purposes, and wherever a clean fire at low cost is required.

Summarizing some of the domains of application of the Jahns ring producer:

Electric Central Stations.—The total cost of generating 1 brake horse-power-hour in ring producers and gas dynamos is only one-half to one-third as compared to the corresponding cost in steam-boiler plants, regardless whether reciprocating piston engines or turbines are used.

Coal Mines. — Utilization of the waste or refuse from coal washing and separation, and of the petrified products and culm, thereby saving valuable boiler coal. A daily consumption of 200 tons of such refuse, which at the present has no value whatsoever, gives an average available output of 7000 h.p. per hour in gas dynamos.

Iron and Steel Industry. — Utilization of producer gas for heating and smelting. Reduction of heat cost by burning low-grade fuels. Simplification of plant operation, as the gas is equally applicable in gas engines for the operation of power, as well as for lighting purposes.

There are, of course, other realms and forms of application, as for instance, in factories, in the cement and ceramic industries, and in the long-distance transmission of gas and electric power from central producer plants.

I want to add a few remarks on the future development of gas producers, so far as it is possible to predict on the basis of an intimate knowledge and careful study of present tendencies and conditions prevailing on the Continent. Since the problem of successfully gasifying the lowest grades of fuel has now been actually solved, the demand for large gas-power plants of this character necessitates the elaboration of units of high capacity. It is obvious that the attempt to increase the output by aggregating a great number of single producers in ordinary combinations or groups must prove a failure for the simple reason that it is uneconomical as regards floor space and cost of construction. It is therefore natural that some German firms should try to follow the same line of thought which has evolved the water-tube boiler from its original form and the retort coke oven from the bee-hive type. In other words, large producer plants will in future consist of a bank of producers, that is, a combination of several series of vertical retorts, which are all inclosed in a common casing, no special house being required. It is needless to point out that the advantages of reduced floor space, decreased heat loss, elimination of piping, diminished cost of labor, and lower initial capital outlay fully justify such practice. The Jahns producer represents the first step in the direction indicated. It is an attempt to create a standard form of gas producer for large-scale operation, which is commercially feasible only when burning the lowest grades of fuel in apparatus specially adapted to their use.

THE MOND PROCESS

Reference has been made already to various processes which transform raw coals of the lignitic and peat class, slack, bituminous coal, mine culm, etc., either directly into gas, or into gas and coke, with the recovery of by-products. The oldest of these processes is that invented by Dr. Mond, characterized by the introduction into the fuel bed of large quantities of steam together with the air blast, in order to increase the yield of ammonia.

The amount of steam required is $2\frac{1}{4}$ tons per ton of coal gasified. The total volume of gas made from a ton of slack varies with the carbon contents of the coal, and ranges from 125,000 to 150,000 cu. ft., measured at 15 deg. Cent. Owing to the abundance of water vapor present, the temperature of the gas when leaving the producer is low, about 450 deg. Cent. It contains from 11 to 12 per cent. CO, from 27 to 29 per cent. H, from 2 to 3 per cent. CH_4, from 15 to 16 per cent. CO_2, and 42 per cent. N, and has a calorific value of about 150 B.t.u. per cubic foot, representing approximately 80 per cent. of the heat value of the coal gasified.

Bituminous coal containing 1.3 per cent. of nitrogen, when gasified in Mond producers will yield about 90 pounds of sulphate of ammonia per ton of coal, having a value of about \$2. The net profit from the by-product recovery with sulphate of ammonia at \$57 per ton, — after deducting all internal requirements, — is about \$1.10 per ton of slack. A diagrammatic view of the working process is given in Fig. 160. Besides the fundamental improvements referred to by Dr. Caro, there have lately many refinements been made in the mechanical construction of these plants. They refer chiefly to the spraying and washing part of the process, that is, the intimate mixing of gas and acid, which reacts with the nitrogen contained in it. It is obvious that a successful action will make it possible to use a much smaller percentage of acid in the liquid, while at the same time a greater yield of sulphate is obtained. Naturally, the advantages of the weaker acid solution are very considerable, as both the working costs and the rate of deterioration of the plant are appreciably reduced.

The rotary washer employed by Crossley consists of a box fitted with revolving paddles through which the gas is made to pass after the tar, etc., has been removed. This washer takes the place of the acid tower in the Mond plant. With simpler and cheaper means for washing it follows that recovery apparatus can be advantageously fitted on plants which are much smaller than those in connection with which the original Mond process could be profitably employed.

BY-PRODUCT GAS PRODUCERS FOR STEEL WORKS

Quite similar to the Mond system is another producer process which is employed by the Gas Power and By-Products Company,

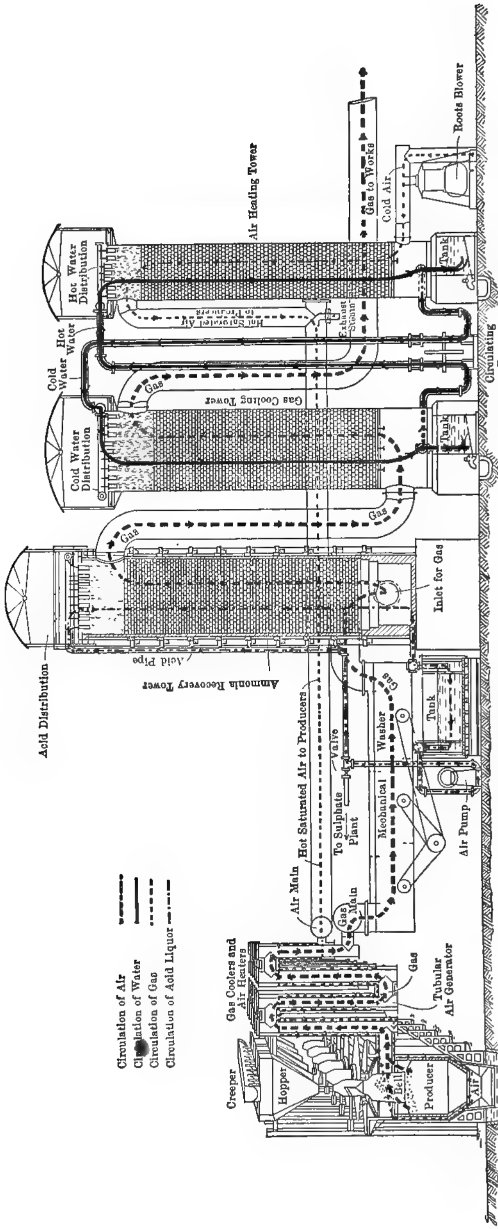


FIG. 160.—Sectional Diagram, Showing General Arrangement of Mond By-Product Recovery Gas Plant.

Ltd., in Glasgow, Scotland, with which several European steel works have been recently equipped.

In a plant which gasifies in producers about 200 tons of coal a day, and where coal costs $2 per ton, causing an expenditure for fuel of $400 daily, the producer gas is used for a variety of purposes, including the smelting of steel, after certain by-products have been extracted from it. The recovery of ammonia varies with the quality of coal used, but averages 30 to 40 kg. or 66 to 88 pounds per ton. This with a total daily coal consumption of 200 tons would mean a recovery of at least 7 tons of sulphate of ammonia, bringing 7 by 57 = $400 per diem. The recovery and sale of this one by-product will, therefore, cover the total fuel expenditures of the plant. In other words, the adoption in a steel plant of by-product gas producers will reduce the self cost of raw steel by from 50 to 75 cents per ton.

This cost reduction added to the saving which can be realized by the rational utilization of blast furnace and coke-oven gases in lage gas engines, amounting as it does to from 60 cents to $1.25 per ton of pig iron made, according to locality, is certainly large enough to commend itself urgently to the attention of every thoughtful and progressive iron-maker.

TABLE I — CONVERSION FACTORS — LINEAL

Millimeter	1.	10.	25.4	304.8	914.4	1000.	.....	.....	.....
Centimeter	.1	1.	2.54	30.48	91.44	100.00	.....	.....	.....
Inch	.03937	.39370	1.	12.00	36.00	39.37	39370.	63360.	72960.
Foot	.00328	.03280	.08333	1.	3.00	3.28083	3280.	5280.	6080.
Yard	.00109	.01093	.02778	.33333	1.	1.093611	1093.	1760.	2026.66
Meter	.00100	.01000	.0254	.304801	.914402	1.	1000.0	1609.35	1853.19
Kilometer	.000001	.00001	.000025	.000315	.000914	.00100	1.	1.60935	1.85319
Miles	.00000062	.0000062	.0000158	.000189	.000568	.000621	.62137	1.	1.1515
Knots	.00000054	.0000052	.0000137	.0001645	.0004934	.00054	.53961	.8684	1.

TABLE II — CONVERSION FACTORS — SURFACE

Square Millimeters	1.	100.	645.2	92900.	836100.	1000000.
Square Centimeters	.01	1.	6.452	927.	8361.	10000.
Square Inches	.00155	.155	1.	144.	1296.	1550.016
Square Feet	......	.001077	.00694	1.	9.	10.764
Square Yards	......	.00012	.00077	.11111	1.	1.196
Square Meters	......	.0001	.000645	.0929	.836	1.

TABLE III — CONVERSION FACTORS — CUBICAL

Cubic Centimeters	1.	16.387	1000.	3785.4	28315.	764552.	1000000.
Cubic Inches	.061	1.	61.023	231.	1728.	46656.	61023.
Liters or Cubic Decimeters	.001	.016387	1.	3.785	28.315	764.55	1000.
Gallons	.000264	.00433	.26417	1.	7.48	201.97	264.17
Cubic Feet	.000035	.000578	.035314	.13368	1.	27.	35.314
Cubic Yards	.0000013	.0000214	.001308	.00495	.037037	1.	1.308
Cubic Meters	.0000010	.000016	.001000	.003785	.02832	.765	1.

1 Liter = 33.81 fl. ozs. 1 Gal. = 128 fl. ozs. 1 Qt. = 32 fl. ozs. 1 fl. oz. = 29.57 cu. cms.

TABLE IV — Conversion Factors — Weight

Grains	1.	15.432	437.5	7000.	15432.36	14000000.	15680000.
Grams	.064799	1.	28.349	453.59	1000.	907180.	1016041.6
Ounces Avoirdupois	.002280	.03527	1.	16.	35.274	32000.	35840.0
Pounds Avoirdupois	.000143	.002205	.0625	1.	2.2046	2000.	2240.0
Kilograms	.000064	.001	.02835	.45359	1.	907.18	1116.04

1 short ton = 2000 lb. = 907.18 kg. 1 long ton = 2240 lb. = 1016.04 kg.

TABLE V — Conversion Factors — Pressure

Atmospheres	1.	.06803	.03342	.02947	.001316	.0004726	.00009677
Pounds per sq. inch	14.7	1.	.4913	.4332	.01934	.006947	.001423
Inches of Mercury 32°F	29.922	2.036	1.	.8818	.03937	.01414	.002895
Feet of Water 60°F	33.94	2.309	1.134	1.	.04464	.01603	.003283
Millimeters of Mercury 32°F	760.	51.7	25.398	22.399	1.	.3592	.07355
Pounds per sq. foot	2116.	143.946	70.7	62.35	2.784	1.	.2048
Kilograms per sq. meter	10333.	702.925	345.331	304.566	13.506	4.883	1.

TABLE VI — Conversion Factors — Power

Foot-pounds per min.	1.	....	44.2567	60.	433.980	....	....	....	33000.	44256.7
Kg. — meters per min.	....	1.	6.11872	8.29532	60.	....	....	....	4562.42	6118.7
Watts	.0225954	0.163433	1.	1.35573	9.805	17.5816	31.6469	69.7696	745.650	1000.
Foot-pounds per sec.	....	....	0.737612	1.	....	....	....	....	550.	737.612
Kg. — meters per sec.	....	....	0.102979	....	1	....	....	....	76.040	101.979
B. T. U.'s per min.	....	....	0.0568776	....	....	1	....	....	42.4108	56.8776
Lbs. Centigrade per min.	....	....	0.0315987	....	....	....	1.	....	23.5615	31.5987
Kg. — deg. Cent. large calories	....	....	0.0143329	....	....	....	....	1.	10.6873	14.3329
Horse-power	....	....	0.0013411	0.00181818	0.0131509	0.0235789	0.042442	0.093568	1.	1.3411
Kilowatts	....	....	0.001	0.00135573	0.0098059	0.0175816	0.0316469	0.069769	0.74565	1

1 English h. p. = 1.014 metric h. p. 1 metric h. p. = 0.986 English h. p.

TABLE VII — Conversion Factors — Heat Energy

Joules	1.	1.35573	9.80596	745.659	1000.	1054.90	1898.81	3600.	4186.17	2684340.	3600000.
Foot-pounds	0.737612	1.	7.23300	550.	737.612	778.104	1400.59	2655.4	3087.77	1980000.	2655403.
Kilogram Meters	0.101979	0.138255	1.	76.0404	101.979	107.577	193.639	367.123	426.900	273745.	367123.
H. P. Sec.	0.001341	0.001818	0.0131509	1.	....	1 4147	2.5465	4.828	5.61412	3600.	4828.
K. W. Sec.	0.001	0.00135573	0.00980596	....	1	1 0549	1.8988	3.6	4.18617	....	....
B. T. U.	0.0009479	0.00128517	0.00929567	....	....	1.	1.8000	3.41266	3.96832	2544.65	3412.66
Pound Cent.	0.0005266	0.000713986	0.00516426	....	....	.5555	1.	1.89592	2 20462	1413.69	1895.92
Watt Hour	0.00027777	0.000376591	0.00272388	0.207125	0.277778	.29302	0.52744	1.	1.16282	745.650	1000.
Large Calories	0.000238882	0.000323859	0.00234247	....	....	.25199	0.45359	0.859975	1.	641.240	859.975
Horse-power-Hour	0.	0.00000050505	0.	....	....	.000392982	0.00070736	0.0013411	0.0015594	1.	1.34111
K. W. Hr.	0.	0.000000376591	0.0000027238	....	....	.000293027	0.00052744	0.001	0.0011628	0.74565	1.

1 B. t. u./lb. = 0.556 cal./kg. 1 B. t. u./cu. ft. = 8.9 cal./cu. m.
1 cal./kg. = 1.80 B. t. u./lb. 1 cal./cu. m. = 0.112 B. t. u./cu. ft.

DEFINITION OF TERMS

JOULE = Watt Second = Energy expended in one second by one standard ampere flowing through a resistance of one standard ohm.
FOOT-POUND = 1 ÷ 778 B. T. U.'s = Energy expended by the force of one pound working through a distance of one foot.
KILOGRAM-METER = 7.233 foot-pounds = Energy expended by the force of one kilogram working through a distance of one meter.
HORSE-POWER = 33,000 foot-pounds per min. = Work done by 33,000 foot-pounds of energy exerted in one minute = 550 foot-lbs. per sec.
KILOWATT = 1,000 watts = Kilowatt second = Work at the rate of one Joule per second.
B. T. U. (British Thermal Unit) = 778 + Foot-pounds Heat required to raise the temperature of one pound of water one degree F. at temperature of max. dens. 39°F.
POUND CENTIGRADE = 1400.59 foot-pounds = Heat required to raise the temperature of one pound of water one degree C. at temperature of max. dens. 4°C.
CALORIE — Large — 3087.77 foot-pounds = Heat required to raise the temperature of one kilogram of water one degree C. at temperature of max. dens. 4°C.

TABLE VIII — Comparison of Thermometers

Temperature Fahrenheit = $\frac{9}{5}$ or 1.8 × Temp. C. + 32 deg.
Temperature Centigrade = $\frac{5}{9}$ or .555 × (Temp. F. — 32) deg.

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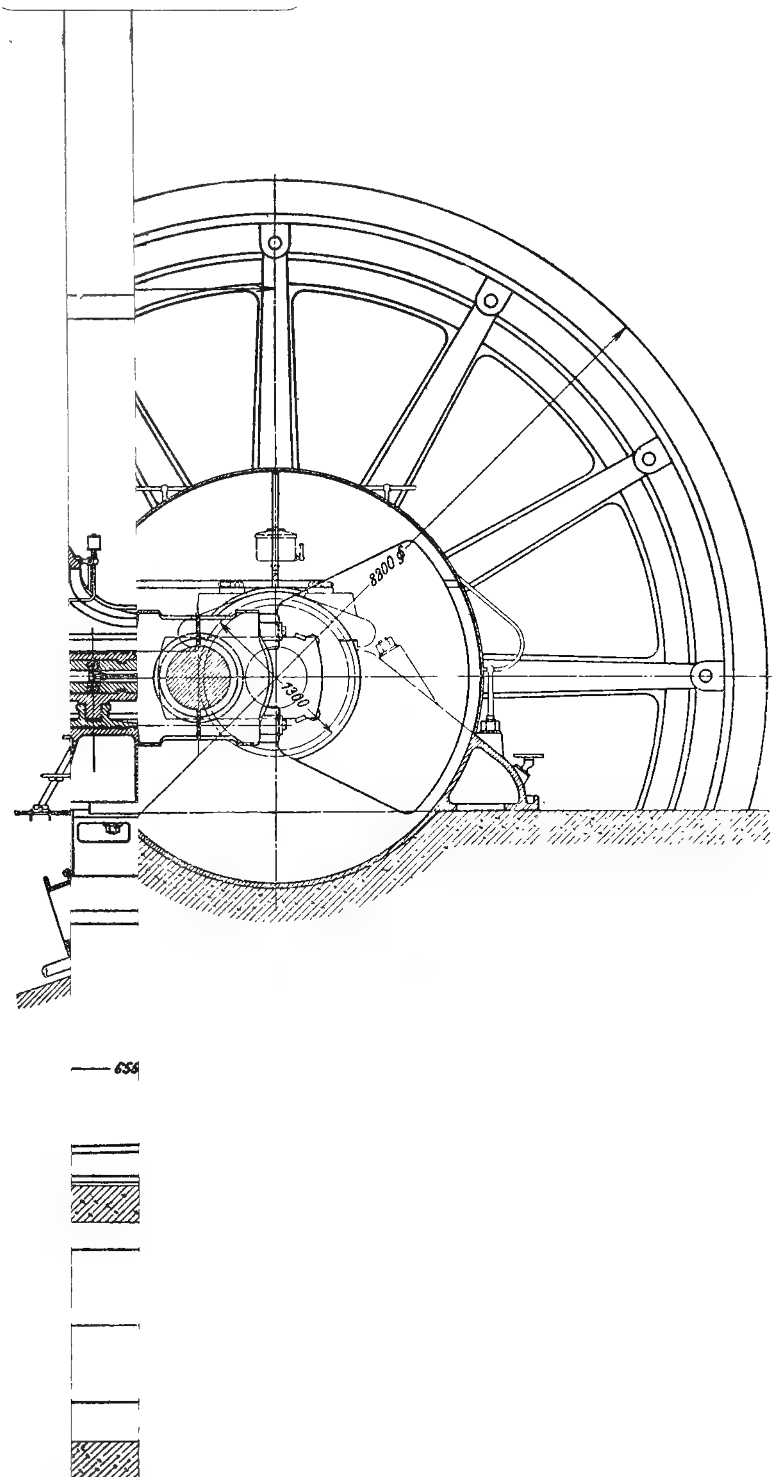

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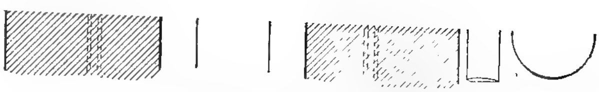
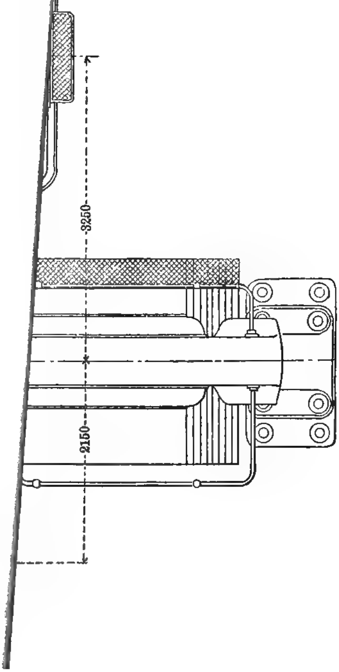


PLATE III. — Cross Section of Nürnberg 2000-H.P. Tandem Gas Engine.



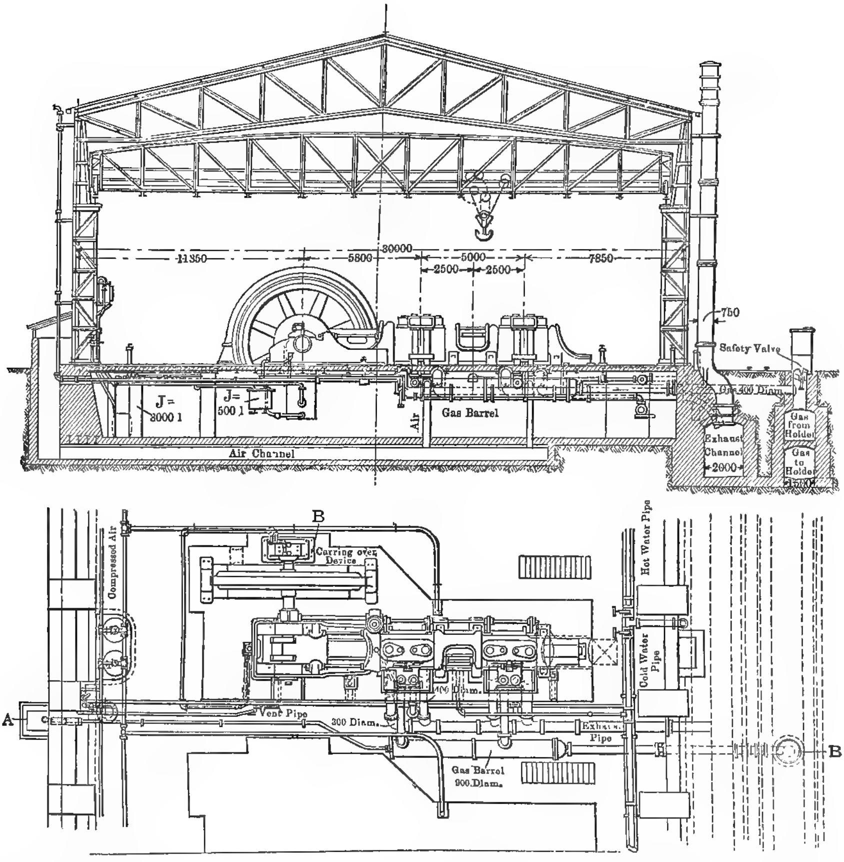


PLATE VII. — Complete Gas Power Plant, Hasper Iron and Steel Works; 1500-Horse-power Nürnberg Engine.